**Findings of the Suisun Marsh Salinity Control Gate Steering Group Technical Team**
**January 2001**

## Findings

The Suisun Marsh Salinity Control Gate Technical Team analyzed the data collected during the 1998 and 1999 salmon passage studies in Montezuma Slough. Results from 1998 and 1999 indicate that the modified flashboards are not improving salmon passage at the SMSCG. Ten environmental factors which may have influenced salmon passage at the gates were also analyzed. The environmental factors were not a significant influence on salmon passage. The Technical Team concluded that the modified flashboards hampered salmon passage and that to improve passage, the focus must shift back to the structure itself.

## Background

Two years of a planned three-year test modification of the SMSCG for salmon passage improvement were completed in 1998 and 1999. In March 2000, the SMSCG Steering Group proposed four options for how to proceed with studies at the SMSCG. The four options were:

1) continue with the third year of the study as planned,
2) take a year to allow the Technical Team to fully analyze the current data,
3) pursue offsite mitigation, and
4) design a new modification of the flashboards for testing in Fall 2000.

Department of Water Resources and the United States Bureau of Reclamation decided to pursue the second option and fully analyze the current data. The SMSCG Technical Team, comprised of staff from the Department of Fish and Game and DWR, was charged with completing the analyses of the 1998 and 1999 salmon studies data and, if possible, determining why salmon were not using the modified flashboards for passage.

## Analyses and Results

The Technical Team addressed two basic questions in their analyses: 1) what are the results of the 1998 and 1999 studies, and 2) what are the factors that could influence salmon passage at the SMSCG. To address the first topic the Technical Team discussed the appropriateness of the criteria (such as station location, number of signals, etc.) that were used to determine salmon passage in 1993, 1994, 1998, and 1999. After much discussion and consultation with Sonotronics, the sonic tag manufacturer, the Technical Team decided that the criteria used in each year were appropriate and did not need to be reevaluated. Following that determination, the 1998 and 1999 study data were fully analyzed.

The Technical Team conclusions about salmon passage at the SMSCG based on results from 1993, 1994, 1998, and 1999 studies are as follows:

- Salmon took significantly longer to pass the gates in the full bore operation phase than in the fully open phase in 1993. There was no (statistical) difference in passage times between these phases in 1994, 1998 and 1999. (Full bore operation is regular flashboards installed, gates and boat lock operating.)

- Significantly fewer salmon passed the gates during the full bore operation phase than the fully open phase in 1993 and 1998. There was no (statistical) difference in passage numbers between these phases in 1994 and 1999. (When comparing numbers that passed in the fully open phase in 1993 with other years, the small sample size due to fish mortalities (27% of the sample number) not counted in the analysis could affect the results. This could be especially true in the '93/'94 versus '98/'99 passage number comparisons.)

- The largest number of fish passed the gates during the fully open phase in 1998 and 1999.

- The smallest number of fish passed the gates during the modified operation phase in 1998 and 1999. These numbers are significantly less than in the other two phases.

- The proportion of salmon passing during the fully open phase was the same (not statistically different) in 1993, 1994 and 1998.

- The proportion of salmon passing during the full bore operation phase was the same (not statistically different) in all four years of the study.

- Salmon took significantly longer to pass the gates during the modified flashboard phase than the other two phases in 1998 but not in 1999.

- There was no significant difference in the numbers of fish that passed during day and night.

- The baseline percentage of no-pass fish for the fully open phase between years was 33%. Assuming this phase would be the same as no impediment to fish passages, we could adjust the numbers of no passage for the other two phases. Even with the adjustment, the modified operation phase would still have the highest incident of no passage.

In addition to the 1993-1999 salmon passage analyses, the Technical Team evaluated ten environmental factors that may affect salmon passage at the SMSCG (Table 1). The Technical Team compiled the list from issues discussed in Steering Group meetings and brain storming sessions. The Technical Team drew three conclusions from the analyses:

- In 1993 and 1994, tidal stage at passage was determined by visual estimations of flow direction and water levels. The Technical Team determined that measured values of flow direction and magnitude are a more accurate representation of tidal phase and should be used in the analyses.

- Flow direction showed a significant affect on salmon passage during the full bore operation phase in 1993 and during the fully open phase in 1994. Salmon were more likely to pass during flood flow than ebb flow in those two years.

- Salinity (represented by specific conductance) did not need to be evaluated extensively because literature (CUWA 1994) indicated that salinity for adult migrating chinook salmon was not a hindrance since they can adjust to salinity levels as low as freshwater (0ppt) and as high as sea water (approximately 34ppt).

| Table. 1. Environmental factors evaluated by the SMSCG Technical Team |
|---|
| Tidal stage |
| Flow direction |
| Types of tide (spring, neap) |
| Phase of the moon |
| Day vs. night |
| Salinity within Montezuma Slough |
| Duration of gate openings |
| Water temperature and dissolved oxygen |
| Magnitude of flow |
| Delta outflow |

The rest of the analyses either showed no affect on salmon passage or the analyses could not be done because the salmon studies were not designed to address the questions.

The following pages provide a detailed description of each of the analyses that were done for the 1993-1999 data, including the analyses of factors that may influence salmon passage.

| **Analysis** | **Page** |
|---|---|
|  |

Null Hypothesis: The amount of time it took tagged salmon to pass the gates during each of the three study phases in 1998 is the same. Study phases are defined as

- everything out of the water,
- regular flashboards installed and gates operated full bore, and
- modified flashboards installed and gates operated full bore.

Alternative Hypothesis: The amount of time it took tagged salmon to pass the gates during each of the three study phases in 1998 is different.

Phases tested during the study are as noted:
Phase I - Normal gate operations with flashboards in place and gates tidally cycled.
Phase II - Non-operation configuration with flashboards out and gates up.
Phase III - Full gate operation with slot openings between flashboards, gates tidally cycled.

Mean Fish Passage Times in Hours

| Phase I | Phase II | Phase III |
|---|---|---|
| 25.8 SD ± 22.5 | 29.8 SD ± 43.4 | 99.5 SD ± 75.6 |
| Range (2.1 - 101.8) | Range (1.2 - 181) | Range (8 - 234.8) |

An Analysis of Variance Test indicated that a significant difference occurred between fish passage times for phases I, II and III. The ANOVA calculated an F Ratio of 15.9312 and a P value of 0.000001. A Kruskal-Wallis test also indicated a significant difference between passage times, Kruskal-Wallis Test Statistic of 18.874214 and a P value of 0.00008.

A Tukey multiple comparison test was done in order to look at the differences in mean passage times between the three phases. The results are listed below:

Comparison of means with Tukey Test:

| Phase Comparison | Difference | SE | q | q,0.05, ,3 | Conclusion |
|---|---|---|---|---|---|
| I vs. II | 4.3 | 8.476 | 0.4900 | 3.39 | Accept $H_{o,}$ I = II |
| I vs. III | 73.7 | 10.008 | 7.3651 | 3.39 | Reject $H_o$, I = III |
| II vs. III | 69.7 | 9.213 | 7.5339 | 3.39 | Reject $H_o$, II = III |

The results indicate that there are significant differences in mean fish passage times when phases I and II are compared to phase III. There was no significant difference in fish passage times when phase I was compared to phase II.

Null Hypothesis: The number of tagged salmon passing the gates during each of the three study phases in 1998 are the same.  Study phases are defined as

- everything out of the water (everything out),
- regular flashboards installed and gates operated full bore (full bore operation), and
- modified flashboards installed and gates operated full bore (modified operation).

Alternative Hypothesis: The number of tagged salmon passing the gates during each of the three study phases in 1998 are different.

Methods: A 2 x 2 chi-square comparison of the number of tagged fish passing and not passing the salinity control gates by phase was used to determine if there were any significant differences in the passage rates.  In 1998, Phase I = regular flashboards in place, gates full bore.  Phase II = everything out of the water, and Phase III = modified flashboards in place, gates operated.

Results[1]:

- Full bore operation compared with everything out resulted in a chi-square value of 4.923 and a $P = 0.027$.*
- Full bore operation compared with modified operation resulted in a chi-square value of 4.384 and a $P = 0.036$.*
- Everything out compared with modified operation resulted in a chi-square value of 18.70 and a $P = 0.00001$.*****

[1]See Table 2.

* Significant difference

Discussion: Comparing the difference in fish passage between phases in 1998 showed a significant difference ($P < 0.05$) between all of the phases.  In this case, we must reject the Null Hypothesis that the number of tagged salmon passing the gates during each phase are the same, and accept the Alternative Hypothesis that the number of salmon passing the gates is different for each operational phase of the salinity control gates.

(Table 2 is on the next page.)

| Table 2. 1998 Comparison of Phases | | | | |
|---|---|---|---|---|
| 1998 Phase I (full bore operation) vs Phase II (everything out) | | | | |
| | Passed | Not Passed | Total | |
| Phase I | 26(31.36) | 23(17.64) | 49 | df = 1 |
| Phase II | 40(34.56) | 14(19.44) | 54 | X2 = 4.923 |
| Totals | 66 | 37 | 103 | *P* = 0.027* |
| 1998 Phase I (full bore operation) vs Phase III (modified operation) | | | | |
| | Passed | Not Passed | Total | |
| Phase I | 26 | 23 | 49 | df = 1 |
| Phase III | 18 | 37 | 55 | X2 = 4.384 |
| Totals | 44 | 60 | 104 | *P* = 0.036* |
| 1998 Phase II (everything out) vs Phase III (modified operation) | | | | |
| | Passed | Not Passed | Total | |
| Phase II | 40 | 14 | 54 | df = 1 |
| Phase III | 18 | 37 | 55 | X2 = 18.70 |
| Totals | 58 | 51 | 109 | *P* = 0.00001* |
| df = degrees of freedom, X2 = chi-square value, *P* = probability number | | | | |

Null Hypothesis: The amount of time it took tagged salmon to pass the gates during each of the three study phases in 1999 is the same. Study phases are defined as

- everything out of the water,
- regular flashboards installed and gates operated full bore, and
- modified flashboards installed and gates operated full bore.

Alternative Hypothesis: The amount of time it took tagged salmon to pass the gates during each of the three study phases in 1999 is different.

Phases tested during the study are as noted:
Phase I – Normal gate operations with flashboards in place and gates tidally cycled.
Phase II– Non-operation configuration with flashboards out and gates up.
Phase III – Full gate operation with slot openings between flashboards, gates tidally cycled.

Mean Fish Passage Times in Hours

| Phase I | Phase II | Phase III |
|---|---|---|
| 68.9 SD ± 62.3 | 42 SD ± 37.9 | 74.6 SD ± 80.1 |
| Range (3.3-190.8) | Range (2.8-126.4) | Range (2.3-210.4) |

An Analysis of Variance Test indicated that no significant difference occurred between fish passage times for phases I, II and III. The ANOVA calculated an F Ratio of 2.302 and a P value of 0.1073. A Kruskal-Wallis test also indicated no significant difference between passage times, Kruskal-Wallis Test Statistic of 2.322 and a P value of .3130.

Conclusion that there is no significant difference between fish passage times for the three operational phases. Accept $H_o$, I = II = III.

Null Hypothesis: The number of tagged salmon passing the gates during each of the three study phases in 1999 are the same. Study phases are defined as

- everything out of the water,
- regular flashboards installed and gates operated full bore, and
- modified flashboards installed and gates operated full bore.

Alternative Hypothesis: The number of tagged salmon passing the gates during each of the three study phases in 1999 are different.

Methods: A 2 x 2 chi-square comparison of the number of tagged fish passing and not passing the salinity control gates by phase was used to determine if there were any significant differences in the passage rate. In 1999, Phase I = regular flashboards in place, gates full bore. Phase II = everything out of the water, and Phase III = modified flashboards in place, gates operational.

Results[1]:

- Full bore operation compared with everything out resulted in a chi-square value of 0.22 and a $P = 0.639$.
- Full bore operation compared with modified operation resulted in a chi-square value of 5.565 and a $P = 0.018$.*
- Everything out compared with modified operation resulted in a chi-square value of 7.946 and a $P = 0.005$.*

*Significant difference
[1]See Table 3

Discussion: Comparing the difference in fish passage between phases in 1999 showed a significant difference (P = <0.05) in Phases I (full bore operation) and II (everything out) with Phase III (modified operation). In comparing Phase I and II, we must accept the Null Hypothesis that passage rates are the same. In the case of Phase III, when compared with I and II, we have to reject the Null Hypothesis and conclude that passage is significantly different.

(Table 3 is on the next page.)

| Table 3. Comparison of passage numbers for 1999 | | | | |
|---|---|---|---|---|
| 1999 Phase I (everything out) vs Phase II (full bore operation) | | | | |
| | Passed | Not Passed | Total | |
| Phase I | 28 | 30 | 58 | df = 1 |
| Phase II | 31 | 28 | 59 | X2 = 0.22 |
| Totals | 59 | 58 | 117 | *P* = 0.639 |
| 1999 Phase I (everything out) vs Phase III (modified operation) | | | | |
| | Passed | Not Passed | Total | |
| Phase I | 28 | 30 | 58 | df = 1 |
| Phase III | 16 | 43 | 59 | X2 = 5.565 |
| Totals | 44 | 73 | 117 | *P* = 0.018* |
| 1999 Phase II (full bore operation) vs Phase III (modified operation) | | | | |
| | Passed | Not Passed | Total | |
| Phase II | 31 | 28 | 59 | df = 1 |
| Phase III | 16 | 43 | 59 | X2 = 7.946 |
| Totals | 47 | 71 | 118 | *P* = 0.005* |
| (df = degrees of freedom, X2 = chi-square value, *P* = probability number) | | | | |

Null Hypothesis: The numbers of tagged salmon that passed the gates during each of the three study phases in 1998 are the same as the numbers of tagged salmon that passed the gates in 1999. Study phases are defined as

- everything out of the water,
- regular flashboards installed and gates operated full bore, and
- modified flashboards installed and gates operated full bore.

Alternative Hypothesis: The numbers of tagged salmon that passed the gates during each of the three study phases in 1998 are different from the numbers of tagged salmon that passed the gates in 1999.

Methods: A 2 x 2 chi-square comparison of the number of tagged fish passing and not passing the salinity control gates for 1998 and 1999 between each phase was used to determine if there was any significant difference in the passage rate. For both years, Phase I = regular flashboards in place, gates full bore, Phase II = everything out of the water and, Phase III = modified flashboards in place, gates full bore.

Results[1]:

- Full bore operation-1998 compared with full bore operation-1999 resulted in a chi-square value of 0.252 and a P = 0.616.
- Everything out-1998 compared with everything out-1999 resulted in a chi-square value of 5.609 and a P = 0.018.*
- Modified operation-1998 compared with modified operation-1999 resulted in a chi-square value of 0.427 and a P = 0.513.
- Total of all phases, 1998 compared with total of all phases, 1999 resulted in a chi-square value of 3.374 and a P = 0.066.

*Significant difference
[1]See Table 4.

Discussion: Comparing the differences in fish passages between phases by year for Phase I (full bore operation) and Phase III (modified operation) showed no significant difference in passage rates ($P > 0.05$). Thus, we must accept the Null Hypothesis for these comparisons. Only the 1998 Phase II (everything out) showed significantly higher passage compared with 1999 Phase II ($P < 0.05$).

(Table 4 is on the next page.)

| Table 4. 1998 vs 1999 Comparison of Phases by Year | | | | |
|---|---|---|---|---|
| 1998 Full Bore Operation vs 1999 Full Bore Operation | | | | |
| | Passed | Not Passed | Total | |
| ‘98 Phase I | 26 | 23 | 49 | df = 1 |
| ‘99 Phase I | 28 | 30 | 58 | X2 = 0.252 |
| Totals | 54 | 53 | 107 | *P* = 0.616 |
| 1998 Everything Out vs 1999 Everything Out | | | | |
| | Passed | Not Passed | Total | |
| ‘98 Phase II | 40 | 14 | 54 | df = 1 |
| ‘99 Phase II | 31 | 28 | 59 | X2 = 5.609 |
| Totals | 71 | 42 | 113 | *P* = 0.018* |
| 1998 Modified Operation vs 1999 Modified Operation | | | | |
| | Passed | Not Passed | Total | |
| 98 Phase III | 18 | 37 | 55 | df = 1 |
| 99 Phase III | 16 | 43 | 59 | X2 = 0.427 |
| Totals | 34 | 80 | 114 | *P* = 0.513 |
| 1998 Total All Phases vs 1999 Total All Phases | | | | |
| | Passed | Not Passed | Total | |
| 98 All Phases | 84 | 74 | 158 | df = 1 |
| 99 All Phases | 75 | 101 | 176 | X2 = 3.374 |
| Totals | 159 | 175 | 334 | *P* = 0.066 |
| (df = degrees of freedom, X2 = chi-square value, *P* = probability number) | | | | |

Null Hypothesis: The numbers of tagged salmon that passed the gates during each of the three study phases in 1993, 1994, 1998, and 1999 are the same. Study phases are defined as

- everything out of the water,
- regular flashboards installed and gates operated full bore,
- modified flashboards installed and gates operated full bore, and
- regular flashboards installed, gates out of the water and not operated.

Alternative Hypothesis: The numbers of tagged salmon that passed the gates during each of the three study phases in 1993, 1994, 1998, and 1999 are different.

Methods: A 2 x 2 chi-square comparison of the number of tagged fish passing and not passing the salinity control gates in the three study phases in '93, '94, '98 and '99 was used to determine if there was any significant difference in the passage rates. In 1993 and 1994, Phase I was everything out of the water, and in 1998 and 1999, Phase II was this configuration. Phase III in 1993 and 1994 was regular flashboards in, gates operated full bore, with Phase I in this configuration for 1998 and 1999. Regular flashboards installed and gates out of the water was Phase II in 1993 and 1994, while in 1998 and 1999 the modified flashboards were in place and gates operated full bore. Due to these differences, I only compared the first two configurations between years.

Results[1]:

- 1993 everything out compared to 1998 everything out resulted in a chi-square value of 1.433 and a $P = 0.231$.
- 1993 everything out compared to 1999 everything out resulted in a chi-square value of 5.619 and a $P = 0.018$.*
- 1994 everything out compared to 1998 everything out resulted in a chi-square value of 0.098 and a $P = 0.757$.
- 1994 everything out compared to 1999 everything out resulted in a chi-square value of 3.663 and a $P = 0.056$.*
- 1993/94 total everything out compared to 1998/99 total everything out gave me a chi-square value of 4.179 and a $P = 0.041$.*
- 1993 full bore operation compared to 1998 full bore operation resulted in a chi-square value of 0.142 and a $P = 0.706$.
- 1993 full bore operation compared to 1999 full bore operation resulted in a chi-square value of 0.019 and a $P = 0.890$.
- 1994 full bore operation compared to 1998 full bore operation resulted in a chi-square value of 0.124 and a $P = 0.724$.
- 1994 full bore operation compared to 1999 full bore operation resulted in a chi-square value of 0.532 and a $P = 0.466$.
- 1993/94 total full bore operation compared to 1998/99 full bore operation gave me a chi-square value of 0.138 and a $P = 0.710$.

[1]See Tables 5 & 6.

*Significant difference

Discussion: Comparing the differences in passage rates between phases by study year showed a significant difference ($P < 0.05$) between 1993 and 1994 Phase I vs. 1999 Phase II (everything out of the water). Comparing the yearly totals for everything out also showed a significant difference in passage. There was not a significant difference in the passage rates for phase III 93/94 vs phase I 98/99 configuration (flashboards in, gates operational), so we must accept the Null Hypothesis that the passage rates are the same.

Table 5. Full Bore Operations: Flashboards in, Gates Operated

| | | | | |
|---|---|---|---|---|
| 1993 Phase III vs 1998 Phase I | | | | |
| | Passed | Not Passed | Total | |
| 1993 | 10 | 10 | 20 | df = 1 |
| 1998 | 26 | 23 | 49 | X2 = 0.142 |
| Total | 36 | 33 | 69 | *P* = 0.706 |
| 1993 Phase III vs 1999 Phase I | | | | |
| | Passed | Not Passed | Total | |
| 1993 | 10 | 10 | 20 | df = 1 |
| 1999 | 28 | 30 | 58 | X2 = 0.019 |
| Total | 38 | 40 | 78 | *P* = 0.890 |
| 1994 Phase III vs 1998 Phase I | | | | |
| | Passed | Not Passed | Total | |
| 1994 | 11 | 8 | 19 | df = 1 |
| 1998 | 26 | 23 | 49 | X2 = 0.124 |
| Total | 37 | 31 | 68 | *P* = 0.724 |
| 1994 Phase III vs 1999 Phase I | | | | |
| | Passed | Not Passed | Total | |
| 1994 | 11 | 8 | 19 | df = 1 |
| 1999 | 28 | 30 | 58 | X2 = 0.532 |
| Total | 39 | 38 | 77 | *P* = 0.466 |
| 93/94 Phase III vs 98/99 Phase I (Combined full bore operation) | | | | |
| | Passed | Not Passed | Total | |
| 93/94 | 21 | 18 | 39 | df = 1 |
| 98/99 | 54 | 53 | 107 | X2 = 0.138 |
| Total | 75 | 71 | 146 | *P* = 0.710 |

df = degrees of freedom, X2 = chi-square value, *P* = probability number
* = significant difference

| Table 6. Everything Out: Flashboards out, Gates up | | | | |
|---|---|---|---|---|
| 1993 Phase I vs 1998 Phase II | | | | |
| | Passed | Not Passed | Total | |
| 1993 | 10 | 1 | 11 | df = 1 |
| 1998 | 40 | 14 | 54 | X2 = 1.433 |
| Total | 50 | 15 | 65 | *P* = 0.231 |
| 1993 Phase I vs 1999 Phase II | | | | |
| | Passed | Not Passed | Total | |
| 1993 | 10 | 1 | 11 | df = 1 |
| 1999 | 31 | 28 | 59 | X2 = 5.619 |
| Total | 41 | 29 | 70 | *P* = 0.0178* |
| 1994 Phase I vs 1998 Phase II | | | | |
| | Passed | Not Passed | Total | |
| 1994 | 14 | 4 | 18 | df = 1 |
| 1998 | 40 | 14 | 54 | X2 = 0.098 |
| Total | 54 | 18 | 72 | *P* = 0.754 |
| 1994 Phase I vs 1999 Phase II | | | | |
| | Passed | Not Passed | Total | |
| 1994 | 14 | 4 | 18 | df = 1 |
| 1999 | 31 | 28 | 59 | X2 = 3.663 |
| Total | 45 | 32 | 77 | *P* = 0.056* |
| ‘93/’94 Phase I vs 98/99 Phase II | | | | |
| | Passed | Not Passed | Total | |
| ‘93/’94 | 24 | 5 | 29 | df = 1 |
| ‘98/’99 | 71 | 42 | 113 | X2 = 4.179 |
| Total | 95 | 47 | 142 | *P* = 0.041* |
| df = degrees of freedom, X2 = chi-square value, *P* = probability number<br>* = Significant difference | | | | |

Null Hypothesis: The amount of time it took tagged salmon to pass the gates during each of the three study phases in 1998 is the same as the amount of time it took tagged salmon to pass in 1999. Study phases are defined as

- everything out of the water,
- regular flashboards installed and gates operated full bore, and
- modified flashboards installed and gates operated full bore.

Alternative Hypothesis: The amount of time it took tagged salmon to pass the gates during each of the three study phases in 1998 is different from the amount of time it took tagged salmon to pass in 1999.

Methods: A 2 x 2 chi-square comparison of the average time of passage between 1998 and 1999 study phases was used to see if any significant difference in the passage times could be seen.

Results[1]:

- Full bore operation vs everything out (1998-99) results were a chi-square value of 3.747 and a $P = 0.053$.*
- Full bore operation vs modified operation (1998-99) results were a chi-square value of 7.016 and a $P = .000$.*
- Everything out vs modified operation (1998-99) results were a chi-square value of 4.919 and a $P = 0.027$.*

*Significant difference
[1]See Table 7.

Discussion: Comparing the differences in passage times between 1998 and 1999 by phases gave me a significant difference ($P < 0.05$) between each phase. Because of this, we must reject the Null Hypothesis that the time passages are the same. Full bore operation passage times were longer than everything out, and the modified operation passage times were longer that both full bore or everything out operational phases.

(Table 7 on the next page.)

Table 7. Comparison of Average Passage Times Between 1998 and 1999 Phases

1998 vs 1999

| | Time (avg.) | Time (avg.) | Total | |
|---|---|---|---|---|
| Full bore operation | 26 | 69 | 95 | |
| Everything out | 30 | 42 | 72 | df = 1 |
| | | | | X2 = 3.747 |
| Totals | 56 | 111 | 167 | *P* = 0.053 |

| | Time (avg.) | Time (avg.) | Total | |
|---|---|---|---|---|
| Full bore operation | 26 | 69 | 95 | |
| Modified operation | 100 | 75 | 175 | df = 1 |
| | | | | X2 = 21.296 |
| Totals | 126 | 144 | 270 | *P* = 0.000 |

| | Time (avg.) | Time (avg.) | Total | |
|---|---|---|---|---|
| Everything out | 30 | 42 | 72 | |
| Modified operation | 100 | 75 | 175 | df = 1 |
| | | | | X2 = 4.919 |
| Totals | 130 | 117 | 247 | *P* = 0.027 |

(df = degrees of freedom, X2 = chi-square value, *P* = probability number)

Null Hypothesis: The numbers of tagged salmon passing the gates during daylight hours between phases but within a year were the same as the numbers passing during night time.

Alternative Hypothesis: The numbers of tagged salmon passing the gates during daylight hours between phases but within a year were different from the numbers passing during night time.

Methods: A 2 x 2 chi-square comparison on day to night passages between phases in each year was used to determine if there was any significant difference in the passage rates of tagged salmon.  Phase I = everything out, Phase II = modified operation, and Phase III = full bore operation.

Results[1]:

- 1993 Everything out vs modified operation  *P* = 0.271
- 1993 Everything out vs full bore operation  *P* = 0.006*
- 1993 Modified operation vs full bore operation  *P* = 0.122
- 1994 Everything out vs modified operation  *P* = 0.072
- 1994 Everything out vs full bore operation  *P* = 0.382
- 1994 Modified operation vs full bore operation  *P* = 0.343
- 1998 Everything out vs full bore operation  *P* = 0.888
- 1998 Everything out vs modified operation  *P* = 0.262
- 1998 Full bore operation vs modified operation  *P* = 0.270
- 1999 Everything out vs full bore operation  *P* = 0.482
- 1999 Everything out vs modified operation  *P* = 0.771
- 1999 Full bore operation vs modified operation  *P* = 0.762

*Significant difference
[1]See Tables 8 & 9.

Discussion: When compared, only 1993 Phase I (everything out) vs Phase III (full bore operation) showed any significant difference in passage ($P < 0.05$).  In all other comparisons there was no significant difference between day and night passage. Therefore we must accept the Null Hypothesis.

Table 8. Comparison of Day to Night Passage by Phase for 1993 and 1994

1993 Phase I (everything out) vs Phase II (modified operation)

| | Day | Night | Total | |
|---|---|---|---|---|
| Phase I | 3 | 7 | 10 | df = 1 |
| Phase II | 4 | 3 | 7 | X2 = 1.212 |
| Totals | 7 | 10 | 17 | *P* = 0.271 |

1993 Phase I (everything out) vs Phase III (full bore operation)

| | Day | Night | Total | |
|---|---|---|---|---|
| Phase I | 3 | 7 | 10 | df = 1 |
| Phase III | 9 | 1 | 10 | X2 = 7.5 |
| Totals | 12 | 8 | 20 | *P* = 0.006* |

1993 Phase II (modified operation) vs Phase III (full bore operation)

| | Day | Night | Total | |
|---|---|---|---|---|
| Phase II | 4 | 3 | 7 | df = 1 |
| Phase III | 9 | 1 | 10 | X2 = 2.388 |
| Total | 13 | 1 | 17 | *P* = 0.122 |

1994 Phase I (everything out) vs Phase II (modified operation)

| | Day | Night | Total | |
|---|---|---|---|---|
| Phase I | 10 | 4 | 14 | df = 1 |
| Phase II | 3 | 6 | 9 | X2 = 3.245 |
| Total | 13 | 10 | 23 | *P* = 0.072 |

1994 Phase I (everything out) vs Phase III (full bore operation)

| | Day | Night | Total | |
|---|---|---|---|---|
| Phase I | 10 | 4 | 14 | df = 1 |
| Phase III | 6 | 5 | 11 | X2 = 0.763 |
| Totals | 16 | 9 | 25 | *P* = 0.382 |

1994 Phase II (modified operation) vs Phase III (full bore operation)

| | Day | Night | Total | |
|---|---|---|---|---|
| Phase II | 3 | 6 | 9 | df = 1 |
| Phase III | 6 | 5 | 11 | X2 = 0.9 |
| Totals | 9 | 11 | 20 | *P* = 0.343 |

(df = degrees of freedom, X2 = chi-square value, *P* = probability number)

Table 9. Comparison of Day to Night Passage by Phase for 1998 and 1999

1998 Phase I (everything out) vs Phase II (full bore operation)

| | Day | Night | Total | |
|---|---|---|---|---|
| Phase I | 10 | 16 | 26 | df = 1 |
| Phase II | 16 | 24 | 40 | X2 = 0.02 |
| Totals | 26 | 40 | 66 | *P* = 0.888 |

1998 Phase I (everything out) vs Phase III (modified operation)

| | Day | Night | Total | |
|---|---|---|---|---|
| Phase I | 10 | 16 | 26 | df = 1 |
| Phase III | 10 | 8 | 18 | X2 = 1.26 |
| Totals | 20 | 24 | 44 | *P* = 0.262 |

1998 Phase II (full bore operation) vs Phase III (modified operation)

| | Day | Night | Total | |
|---|---|---|---|---|
| Phase II | 16 | 24 | 40 | df = 1 |
| Phase III | 10 | 8 | 18 | X2 = 1.215 |
| Totals | 26 | 32 | 58 | *P* = 0.270 |

1999 Phase I (everything out) vs Phase II (full bore operation)

| | Day | Night | Total | |
|---|---|---|---|---|
| Phase I | 11 | 17 | 28 | df = 1 |
| Phase II | 15 | 16 | 31 | X2 = 0.495 |
| Totals | 26 | 33 | 59 | *P* = 0.482 |

1999 Phase I (everything out) vs Phase III (modified operation)

| | Day | Night | Total | |
|---|---|---|---|---|
| Phase I | 11 | 17 | 28 | df = 1 |
| Phase III | 7 | 9 | 16 | X2 = 0.085 |
| Totals | 18 | 26 | 44 | *P* = 0.771 |

1999 Phase II (full bore operation) vs Phase III (modified operation)

| | Day | Night | Total | |
|---|---|---|---|---|
| Phase II | 15 | 16 | 31 | df = 1 |
| Phase III | 7 | 9 | 16 | X2 = 0.092 |
| Totals | 22 | 25 | 47 | *P* = 0.762 |

(df = degrees of freedom, X2 = chi-square value, *P* = probability number)

Null Hypothesis: The numbers of tagged salmon passing the gates during daylight hours between years were the same as the numbers passing during night time.

Alternative Hypothesis: The numbers of tagged salmon passing the gates during daylight hours between years were different from the numbers passing during night time.

Methods: A 2 x 2 chi-square comparison between day and night passage rates was used to determine any significant difference in these rates between years.

Results[1]:
- 1993 vs 1994   $P = 0.787$
- 1993 vs 1998   $P = 0.137$
- 1993 vs 1999   $P = 0.174$
- 1994 vs 1998   $P = 0.198$
- 1994 vs 1999   $P = 0.249$
- 1998 vs 1999   $P = 0.862$

([1] See Table 10)

Discussion: There was no significant difference in the day and night passage rates of tagged salmon when compared by year ($P > 0.05$). Therefore we must accept the Null Hypothesis.

(Table 10 on the following page.)

Table 10. Comparison of Combined Day vs Night by Year

| | Day | Night | Total | |
|---|---|---|---|---|
| 1993 | 16 | 11 | 27 | df = 1 |
| 1994 | 19 | 15 | 34 | X2 = 0.073 |
| Totals | 35 | 26 | 61 | *P* = 0.787 |

| | Day | Night | Total | |
|---|---|---|---|---|
| 1993 | 16 | 11 | 27 | df = 1 |
| 1998 | 36 | 48 | 84 | X2 = 2.208 |
| Totals | 52 | 59 | 111 | *P* = 0.137 |

| | Day | Night | Total | |
|---|---|---|---|---|
| 1993 | 16 | 11 | 27 | df = 1 |
| 1999 | 33 | 42 | 75 | X2 = 1.852 |
| Totals | 49 | 53 | 102 | *P* = 0.174 |

| | Day | Night | Total | |
|---|---|---|---|---|
| 1994 | 19 | 15 | 34 | df = 1 |
| 1998 | 36 | 48 | 84 | X2 = 1.656 |
| Totals | 55 | 63 | 118 | *P* = 0.198 |

| | Day | Night | Total | |
|---|---|---|---|---|
| 1994 | 19 | 15 | 34 | df = 1 |
| 1999 | 33 | 42 | 75 | X2 = 1.327 |
| Totals | 52 | 57 | 109 | *P* = 0.249 |

| | Day | Night | Total | |
|---|---|---|---|---|
| 1998 | 36 | 48 | 84 | df = 1 |
| 1999 | 33 | 42 | 75 | X2 = 0.030 |
| Totals | 69 | 90 | 159 | *P* = 0.862 |

(df = degrees of freedom, X2 = chi-square value, *P* = probability number)

Null Hypothesis: The numbers of tagged salmon passing the gates during daylight hours between phases but all years combined were the same as the numbers passing during night time.

Alternative Hypothesis: The numbers of tagged salmon passing the gates during daylight hours between phases but all years combined were different from the numbers passing during night time.

Methods: A 2 x 2 chi-square comparison of day to night passages combining years between phases to determine if there was a difference in passage rates between phases by year. Phase I = everything out, Phase II = full bore operation, Phase III = modified operation

Results: Combined 1993 through 1999 day/night passage numbers by phase[1].

- Everything out vs full bore operation *P* = 0.259
- Everything out vs modified operation *P* = 0.847
- Full bore operation vs modified operation *P* = 0.431
  ([1] See Table 11.)

Discussion: When compared, there was no significant difference (*P* > 0.05) in the passage rates by combined year and phase so we must accept the Null Hypothesis.

Table 11. Phase by Year Comparison for Day/Night Passage, 1993 through 1999

| | Day | Night | Total | |
|---|---|---|---|---|
| Phase I | 44 | 51 | 95 | df = 1 |
| Phase II | 36 | 29 | 65 | X2 = 1.270 |
| Totals | 80 | 80 | 160 | *P* = 0.259 |
| Phase I | 44 | 51 | 95 | df = 1 |
| Phase III | 24 | 26 | 50 | X2 = 0.037 |
| Totals | 68 | 77 | 145 | *P* = 0.847 |
| Phase II | 36 | 29 | 65 | df = 1 |
| Phase III | 24 | 26 | 50 | X2 = 0.619 |
| Totals | 60 | 55 | 115 | *P* = 0.431 |

(df = degrees of freedom, X2 = chi-square value, *P* = probability)

Null Hypothesis: The numbers of tagged salmon passing the gates during daylight hours during the everything open phase across years were the same as the numbers passing during night time.

Alternate Hypothesis: The numbers of tagged salmon passing the gates during daylight hours during the everything out phase across years were different from the numbers passing during night time.

Methods: A 2 x 2 chi-square comparison on day to night passages in the everything out configuration across years was used to determine any significant difference in passage between night and day.

Results[1]:

- 1993 vs 1994 $P = 0.045$*
- 1998 vs 1999 $P = 0.479$
- 1993 vs 1998 $P = 0.560$
- 1993 vs 1999 $P = 0.308$
- 1994 vs 1998 $P = 0.043$*
- 1994 vs 1999 $P = 0.149$

(*Significant difference)
([1] See Table 12)

Discussion: When compared, only 93 vs 94 and 94 vs 98 in the everything out configuration showed any significant difference ($P < 0.05$) in day vs night passage. For all other year comparisons, we must accept the Null Hypothesis that the passage rates are the same between years.

(Table 12 is on the following page.)

Table 12. Comparison of Day vs Night Passage Rates by Year for Full Open Phase

| | Day | Night | Total | |
|---|---|---|---|---|
| 1993 | 3 | 7 | 10 | df = 1 |
| 1994 | 10 | 4 | 14 | X2 = 4.031 |
| Totals | 13 | 11 | 24 | *P* = 0.045 |

| | Day | Night | Total | |
|---|---|---|---|---|
| 1998 | 16 | 24 | 40 | df = 1 |
| 1999 | 15 | 16 | 31 | X2 = 0.502 |
| Totals | 31 | 40 | 71 | *P* = 0.479 |

| | Day | Night | Total | |
|---|---|---|---|---|
| 1993 | 3 | 7 | 10 | df = 1 |
| 1998 | 16 | 24 | 40 | X2 = 0.339 |
| Total | 19 | 31 | 50 | *P* = 0.560 |

| | Day | Night | Total | |
|---|---|---|---|---|
| 1993 | 3 | 7 | 10 | df = 1 |
| 1999 | 15 | 16 | 31 | X2 = 1.038 |
| Totals | 18 | 23 | 41 | *P* = 0.308 |

| | Day | Night | Total | |
|---|---|---|---|---|
| 1994 | 10 | 4 | 14 | df = 1 |
| 1998 | 16 | 24 | 40 | X2 = 4.104 |
| Totals | 26 | 28 | 54 | *P* = 0.043 |

| | Day | Night | Total | |
|---|---|---|---|---|
| 1994 | 10 | 4 | 14 | df = 1 |
| 1999 | 15 | 16 | 31 | X2 = 2.081 |
| Totals | 25 | 20 | 45 | *P* = 0.149 |

(df = degrees of freedom, X2 = chi-square number, *P*= probability number)

Null Hypothesis: Baseline no passage numbers for the phase when everything is out of the water in 1993, 1994, 1998 and 1999 are the same.

Alternative Hypotheses: Baseline no passage numbers for the phase when everything is out of the water in 1993, 1994, 1998 and 1999 are different.

Methods: A comparison of the percentage of fish that passed vs not passed between years was calculated to see if there was any difference in the passage between years. Total tagged was the number of fish actually tagged and released for the study. Total survived was the revised number minus fish that died during the study and were removed from the calculation.

Results: For the everything out of the water phase of the fish that survived, 33% did not pass the gates (Table 13). During the full bore operation, 48% did not pass, and the modified operation had the largest no passage rate of 62%.

Discussion: Everything out of the water is the phase that closest imitates an unencumbered passage for salmon. The fact that an average of 33% of the fish did not pass can allow us to set this number as a “baseline” percentage of fish that for whatever reason would not have used Montezuma Slough as a passage and to adjust the numbers for full bore and modified operations. Even with adjustments, during the modified operation for all years the highest percentage of non passage occurred.

Table 13. Baseline no passage numbers by phase

| Everything out | Pass | No Pass | Total Tagged | Total Tagged % No Passage | Total Survived % No Passage |
|---|---|---|---|---|---|
| 1993 | 10 | 5 | 15 | 0.33 | 0.33 |
| 1994 | 14 | 5 | 19 | 0.26 | 0.26 |
| 1998 | 40 | 14 | 66 | 0.21 | 0.26 |
| 1999 | 31 | 28 | 66 | 0.42 | 0.47 |
| Average | | | | 0.31 | 0.33 |
| | | | | | |
| Full Operation | | | | | |
| 1993 | 10 | 10 | 20 | 0.50 | 0.50 |
| 1994 | 11 | 9 | 20 | 0.45 | 0.45 |
| 1998 | 26 | 23 | 66 | 0.35 | 0.47 |
| 1999 | 28 | 30 | 66 | 0.45 | 0.52 |
| Average | | | | 0.44 | 0.48 |
| | | | | | |
| Modified | | | | | |
| 1993 | 7 | 8 | 15 | 0.53 | 0.53 |
| 1994 | 9 | 11 | 20 | 0.55 | 0.55 |
| 1998 | 18 | 37 | 66 | 0.56 | 0.67 |
| 1999 | 16 | 43 | 66 | 0.65 | 0.73 |
| Average | | | | 0.57 | 0.62 |

Null Hypothesis:  Number of tagged salmon that passed per day at the SMSCG gates over a range of times scales (phase and between years) is correlated with Sacramento River Dayflow.

Alternative Hypothesis: Number of tagged salmon that passed per day at the SMSCG gates over a range of times scales (phase and between years) is not correlated with Sacramento River Dayflow.

Methods:
Number of tagged salmon that passed per day at the SMSCG gates were plotted against Sacramento River Dayflow at Rio Vista (cfs) for 1993, 1994, and 1998. Sacramento River Dayflow was chosen since Montezuma Slough borders on the Sacramento River, and the assumption is that tagged salmon are of Sacramento River origin.  Data were stratified by Phase I, Phase II, and Phase III for each year.  Tidal day and spring/neap cycles were not examined since no apparent correlation to salmon passage was previously found.  Data from 1999 were not examined due to outflow data not being available.

Results:
Number of salmon passed per day was apparently not correlated with Dayflow in any years (Fig. 1, 2, and 3).  Dayflow generally decreased through the study period and passage peaks occurred independently.  Passage distribution was positively skewed, indicating that passage peaks occurred at the beginning of each phase immediately after tagging and release.

Discussion:
Number of tagged salmon that passed per day at the SMSCG gates was apparently not correlated with Sacramento River dayflow in 1993, 1994, or 1998. Passage peaks and outflow peaks occurred independently, and passage distribution was positively skewed for each phase indicating that salmon passed through Montezuma Slough fairly rapidly.  Rapid movement of salmon passing the SMSCG gates, regardless of phase and year, would discourage the hypothesis that environmental clues or physical-chemical parameters control salmon passage rates.

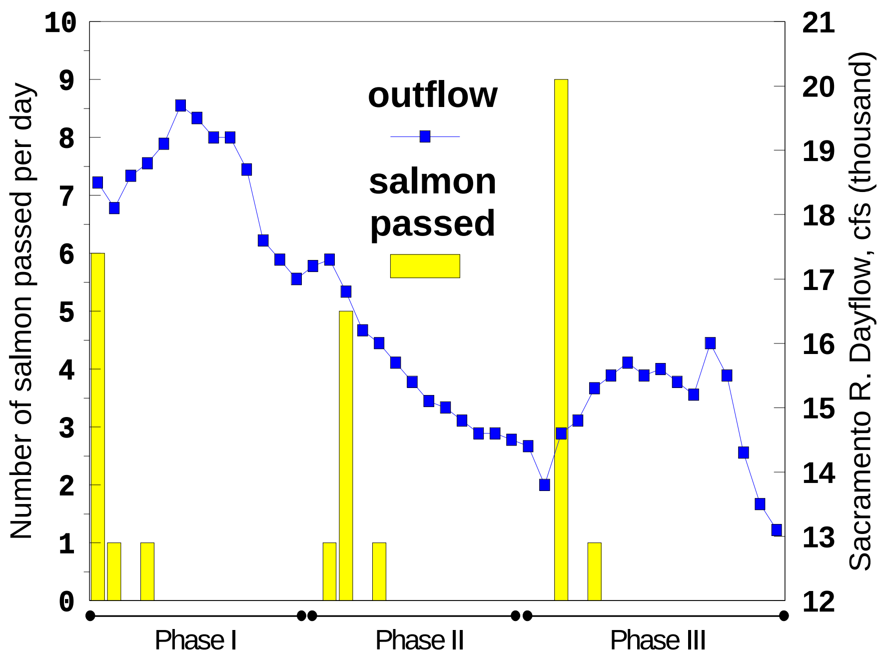



Figure 1. Number of tagged chinook salmon passed per day at the SMSCG plotted against Sacramento River Dayflow in 1993.

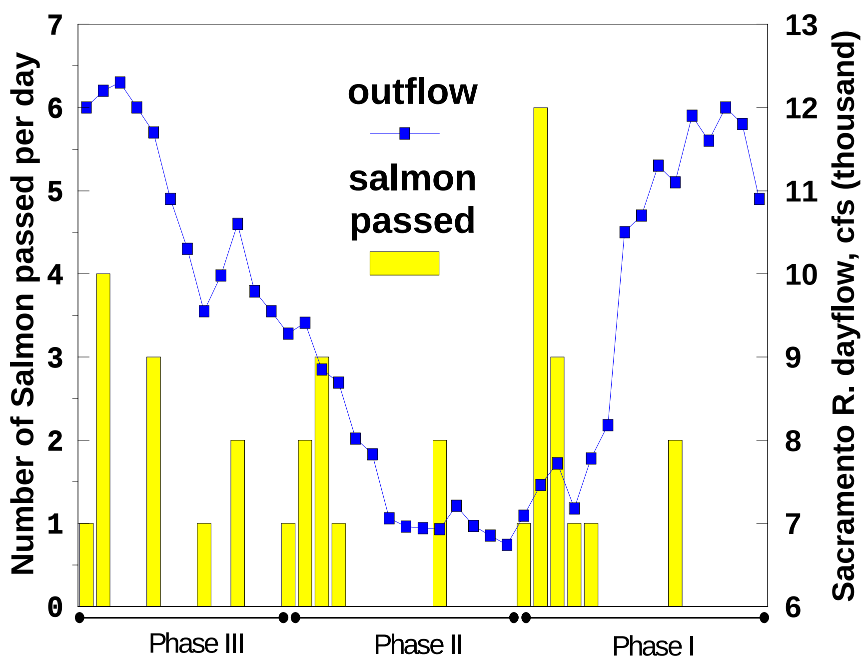



Figure 2. Number of tagged chinook salmon passed per day at the SMSCG plotted against Sacramento River Dayflow in 1994.

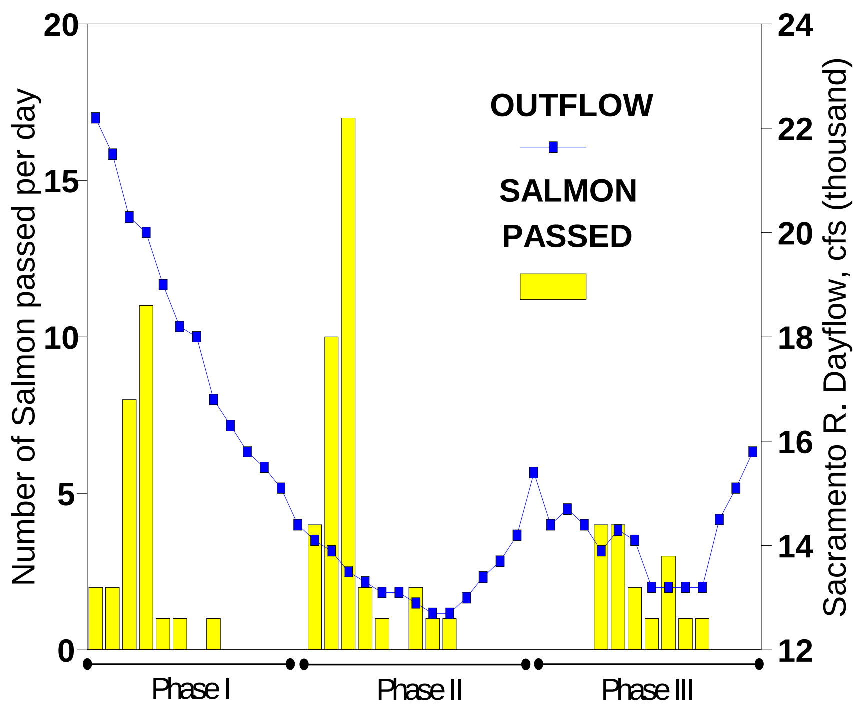



Figure 3. Number of tagged chinook salmon passed per day at the SMSCG plotted against Sacramento River Dayflow in 1998.

Null hypothesis: The magnitude and direction of flow at the SMSCG did not affect whether a tagged salmon would pass the gates during each of the 3 phases in 1993.

Alternative hypothesis: The magnitude and direction of flow at the SMSCG affected whether a tagged salmon would pass the gates during each of the 3 phases in 1993.

Methods: I used a binary logistic regression to test the affect of flow (magnitude and direction) on salmon passage. Fifteen minute flow data from the site glass data set were used for each of the three phases in 1993. The dates of the phases are shown below:

| Table 14. Dates of the 1993 SMSCG salmon study phases | |
|---|---|
| Everything out of the water | 8/23 – 9/6 |
| Flashboards only, no gate operation | 9/7 – 9/16 |
| Full bore operation | 9/17 – 10/4 |

The absolute value of each fifteen minute flow value was calculated to represent the magnitude of flow. Salmon passage times were lined up with the closest 15 minute flow value. For each fifteen minute flow value there was either a “1” indicating a salmon passed the gates or a “0” indicating that no salmon passed the gates. All salmon passage times and gate operation times were converted from Daylight Savings Time to Pacific Standard Time where appropriate. A negative flow value meant flood flow and a positive flow value meant ebb flow. An example of the data is shown below:

| ID | Salmon passage or not | Absolute Flow (cfs) | flow (cfs) | Tidal Phase | Date | PST |
|---|---|---|---|---|---|---|
| 24 | 0 | 3719 | 3719 | ebb | 8/23/93 | 13:45 |
| 25 | 0 | 3646 | 3646 | ebb | 8/23/93 | 14:00 |
| 26 | 0 | 3280 | 3280 | ebb | 8/23/93 | 14:15 |
| Rows 27 – 41 are not shown | | | | | | |
| 42 | 1 | 5583 | -5583 | flood | 8/23/93 | 18:15 |
| 43 | 0 | 5526 | -5526 | flood | 8/23/93 | 18:30 |
| 44 | 0 | 5721 | -5721 | flood | 8/23/93 | 18:45 |

Results:

| Table 15. 1993 Binary Logistic Regression Results for Magnitude of Flow | | | |
|---|---|---|---|
| Phase | P value | Coefficient | Odds Ratio |
| Everything out of the water | 0.06 | 0.0011 | 1.00 |
| Flashboards only, no gate operation | 0.28 | -0.0003 | 1.00 |
| Full bore operation | 0.25 | -0.0003 | 1.00 |

| Table 16. 1993 Binary Logistic Regression Results for Flow Direction | | | |
| --- | --- | --- | --- |
| Phase | P value | Coefficient | Odds Ratio |
| Everything out of the water | 0.72 | -0.445 | 0.64 |
| Flashboards only, no gate operation | 0.35 | 0.826 | 2.28 |
| Full bore operation | 0.01 | -2.902 | 0.05 |

Discussion:
The magnitude of flow, represented by absolute flow, had no affect on when salmon passed the gates regardless of phase (Table 15).

Flow direction has a significant affect on whether salmon passed the gates during the full bore operation phase (Table 16). We hypothesize that the salmon may be moving early in the flooding phase before flow measurements at the SMSCG have met the criteria for closing the gates.

The results from the flow direction regression are similar to results reported by Tillman and others (1996). Tillman and others (1996) reported that most fish (15 of 17 fish) passed the gates on flood or high tide. Our results support the statement as far as flood flow but does not corroborated any tidal stage analyses. In our analysis we examined flow direction based on measured values. Tillman and others (1996) used visual observations to determine "tidal stage at passage." Tidal stage at passage was a combination of flow direction, visual movement of water either north or south, and stage, a visual estimation of water levels.

Citation:
Tillman T., Edwards G., and K. Urquhart. 1996. Adult salmon migration monitoring during the various operational phases of the Suisun Marsh Salinity Control Gates in Montezuma Slough, August-October 1993. Stockton, CA: Department of Fish and Game. 25 p.

Null hypothesis: The magnitude and direction of flow at the SMSCG did not affect whether a tagged salmon would pass the gates during each of the 3 phases in 1994.

Alternative hypothesis: The magnitude and direction of flow at the SMSCG affected whether a tagged salmon would pass the gates during each of the 3 phases in 1994.

Methods: I used a binary logistic regression to test the affect of flow (magnitude and direction) on salmon passage. Fifteen minute flow data from the site glass data set were used for each of the three phases in 1994. The dates of the phases are shown below:

| Table 17. Dates of the 1994 SMSCG salmon study phases | |
|---|---|
| Everything out of the water | 10/28 – 11/14 |
| Flashboards only, no gate operation | 10/11 – 10/24 |
| Full bore operation | 9/26 – 10/8 |

The absolute value of each fifteen minute flow value was calculated to represent the magnitude of flow. Salmon passage times were lined up with the closest 15 minute flow value. For each fifteen minute flow value there was either a “1” indicating a salmon passed the gates or a “0” indicating that no salmon passed the gates. All salmon passage times and gate operation times were converted from Daylight Savings Time to Pacific Standard Time where appropriate. A negative flow value meant flood flow and a positive flow value meant ebb flow. An example of the data is shown below:

| ID | Salmon passage or not | Absolute Flow (cfs) | flow (cfs) | Tidal Phase | Date | PST |
|---|---|---|---|---|---|---|
| 1 | 0 | 2946 | 2946 | ebb | 9/26/94 | 0:00 |
| 2 | 0 | 2873 | 2873 | ebb | 9/26/94 | 0:15 |
| Rows 3 -18 are not shown. | | | | | | |
| 19 | 0 | 895 | -895 | flood | 9/26/94 | 4:30 |
| 20 | 0 | 1587 | -1587 | flood | 9/26/94 | 4:45 |

Results:

| Table 18. 1994 Binary Logistic Regression Results for Magnitude of Flow | | | |
|---|---|---|---|
| Phase | P value | Coefficient | Odds Ratio |
| Everything out of the water | 0.03 | 0.0001 | 1.00 |
| Flashboards only, no gate operation | 0.11 | 0.0008 | 1.00 |
| Full bore operation | 0.92 | -0.00004 | 1.00 |

| Table 19. 1994 Binary Logistic Regression Results for Flow Direction | | | |
|---|---|---|---|
| Phase | P value | Coefficient | Odds Ratio |
| Everything out of the water | 0.04 | -1.931 | 0.15 |
| Flashboards only, no gate operation | 0.44 | -0.563 | 0.57 |
| Full bore operation | 0.80 | -0.203 | 0.82 |

Discussion:
The magnitude of flow, represented by absolute flow, had no affect on when salmon passed the gates regardless of phase (Table 18).

Flow direction had a significant affect on whether salmon passed the gates during the phase when everything was out of the water (Table 19).

The results from the flow direction regression are similar to results reported by Tillman and others (1996). Tillman and others (1996) reported that 53% fish passed the gates on flood or high tide. Our analysis only evaluate flow direction (ebb or flood) and not stage (high or low tide). Tillman and others (1996) used visual observations to determine “tidal stage at passage.” Tidal stage at passage was a combination of flow direction (visual movement of water north, south, or none at all) and stage, a visual estimation of water levels. Our flow values are based on measurements taken by the ultrasonic velocity meter 100 feet south of the SMSCG.

Null hypothesis: The magnitude and direction of flow at the SMSCG did not affect whether a tagged salmon would pass the gates during each of the 3 phases in 1998.

Alternative hypothesis: The magnitude and direction of flow at the SMSCG affected whether a tagged salmon would pass the gates during each of the 3 phases in 1998.

Methods: I used a binary logistic regression to test the affect of flow (magnitude and direction) on salmon passage. Fifteen minute flow data from the site glass data set were used for each of the three phases in 1998. The dates of the phases are shown below:

| Table 20. Dates of the 1998 SMSCG salmon study phases | |
|---|---|
| Everything out of the water | 10/13 – 10/26 |
| Modified flashboards & gates operating | 10/27 – 11/10 |
| Full bore operation | 10/1 – 10/12 |

The absolute value of each fifteen minute flow value was calculated to represent the magnitude of flow. Salmon passage times were lined up with the closest 15 minute flow value. For each fifteen minute flow value there was either a "1" indicating a salmon passed the gates or a "0" indicating that no salmon passed the gates. All salmon passage times were in Pacific Standard Time. Gate operation times were converted from Daylight Savings Time to Pacific Standard Time where appropriate. A negative flow value meant flood flow and a positive flow value meant ebb flow.

Results:

| Table 21. 1998 Binary Logistic Regression Results for Magnitude of Flow | | | |
|---|---|---|---|
| Phase | P value | Coefficient | Odds Ratio |
| Everything out of the water | 0.96 | -0.0000 | 1.00 |
| Modified flashboards & gates operating | 0.26 | 0.0002 | 1.00 |
| Full bore operation | 0.76 | 0.0000 | 1.00 |

| Table 22. 1998 Binary Logistic Regression Results for Flow Direction | | | |
|---|---|---|---|
| Phase | P value | Coefficient | Odds Ratio |
| Everything out of the water | 0.39 | 0.2872 | 1.33 |
| Modified flashboards & gates operating | 0.45 | -0.4125 | 0.66 |
| Full bore operation | 0.07 | -1.1238 | 0.33 |

Discussion:
The magnitude of flow, represented by absolute flow, and flow direction had no affect on when salmon passed the gates regardless of phase in 1998 (Tables 21 & 22).

Null hypothesis: The magnitude and direction of flow at the SMSCG did not affect whether a tagged salmon would pass the gates during each of the 3 phases in 1999.

Alternative hypothesis: The magnitude and direction of flow at the SMSCG affected whether a tagged salmon would pass the gates during each of the 3 phases in 1999.

Methods: I was unable to run a binary logistic regression to test the affect of flow (magnitude and direction) on salmon passage because of missing flow values during the full bore and modified flashboard phases. The data recording system malfunctioned during those phases. However, fifteen minute flow data were available for the everything out phase in 1999. The dates of the phase are shown below:

| Table 23. Dates of the 1999 SMSCG salmon study phase when flow data are available | |
|---|---|
| Everything out of the water | 10/15 – 11/04 |

The absolute value of each fifteen minute flow value was calculated to represent the magnitude of flow. Salmon passage times were lined up with the closest 15 minute flow value. For each fifteen minute flow value there was either a “1” indicating a salmon passed the gates or a “0” indicating that no salmon passed the gates. All salmon passage times were in Pacific Standard Time. Gate operation times were converted from Daylight Savings Time to Pacific Standard Time where appropriate. A negative flow value meant flood flow and a positive flow value meant ebb flow. The data set looks very similar to the examples shown in the 1993, 1994 and 1998 write ups.

Results:

Table 24.1999 Binary Logistic Regression Results for Magnitude of Flow and Flow Direction during the Phase when Everything is Out of the Water

| Factor | P value | Coefficient | Odds Ratio |
|---|---|---|---|
| Magnitude of Flow | 0.52 | 0.0001 | 1.00 |
| Flow direction | 0.99 | -0.0039 | 1.00 |

Discussion:
The magnitude of flow, represented by absolute flow, and flow direction had no affect on when salmon passed the gates when everything was out of the water (Table 24).

Hypothesis: Equal numbers of salmon passed the SMSCG during ebb flow and flood flow during the 1998 and 1999 salmon studies.

Alternative Hypothesis: Unequal numbers of salmon passed the SMSCG during ebb flow and flood flow during the 1998 and 1999 salmon studies.

Methods:
Fifteen minute flow data were plotted for each of the phases of the 1998 and 1999 salmon studies. The flow data were collected by the ultrasonic velocity meter located about 300 feet upstream (north side) of the SMSCG. Flow data were converted to Pacific Standard Time where appropriate. Points were plotted on the flow graph any time a salmon passed the gates. If multiple salmon passed in the same fifteen minute period, passage times were moved to adjacent flow intervals (Table 25). In 1998 12 fish passed in the same fifteen minute interval and 6 fish in 1999. Fish that passed when flow values were missing were plotted on the x-axis. Ebb flow was defined as positive flow values and flood flow was negative flow values.

Table 25. Example of salmon passing in the same fifteen minute flow interval

| Date | PST | flow (cfs) | Fish Passage | Tag # | Actual Passage Time (PST) |
|---|---|---|---|---|---|
| 10/4/98 | 22:15 | 4020 | | | |
| 10/4/98 | 22:30 | 2840 | 2840 | 39 | 22:32 |
| 10/4/98 | 22:45 | 1351 | 1351 | 55 | 22:36 |
| 10/5/98 | 23:00 | 98 | | | |

Results:

Table 26. Numbers of salmon passing on ebb flow, flood flow or during missing flow values in the 1998 and 1999 SMSCG salmon studies

| Year | Phase | # and % passing during ebb flow | # and % passing during flood flow | # and % passing when flow is unknown |
|---|---|---|---|---|
| 1998 | Full bore | 21 (81%) | 5 (19%) | 0 |
| | Modified | 13 (68%) | 6 (32%) | 0 |
| | Fully open | 18 (45%) | 21 (53%) | 1 (2%) |
| 1999 | Full bore | 27 (96%) | 0 | 1 (4%) |
| | Modified | 7 (44%) | 0 | 9 (56%) |
| | Fully open | 14 (47%) | 12 (40%) | 4 (13%) |

| Table 27. Combined numbers of 1998 and 1999 salmon passing on ebb flow, flood flow or during missing flow values | | | |
|---|---|---|---|
| Phase (1998+1999) | # and % passing during ebb flow | # and % passing during flood flow | # and % passing during missing flow values |
| Full bore | 48 (89%) | 5 (9%) | 1 (2%) |
| Modified | 20 (57%) | 6 (17%) | 9 (26%) |
| Fully open | 32 (46%) | 33 (47%) | 5 (7%) |

Figures 4-9 graphically illustrate the passage of tagged salmon at the SMSCG with flow during the 1998 and 1999 studies.

Discussion:
This analysis was done to visually describe the passage of salmon during the ebbing and flooding phases of the tide. The combined 1998 and 1999 results indicate that during the fully open phase, when salmon are free to pass at any time, salmon passed in equal numbers during the ebbing and flooding flows. The combined data for the full bore and modified phases indicate that the majority of salmon are passing during ebb flow when the gates are open.

**Figure 4. Flow at SMSCG (UVM) vs. Time of Salmon Passage**
**Full bore operation - 1998**

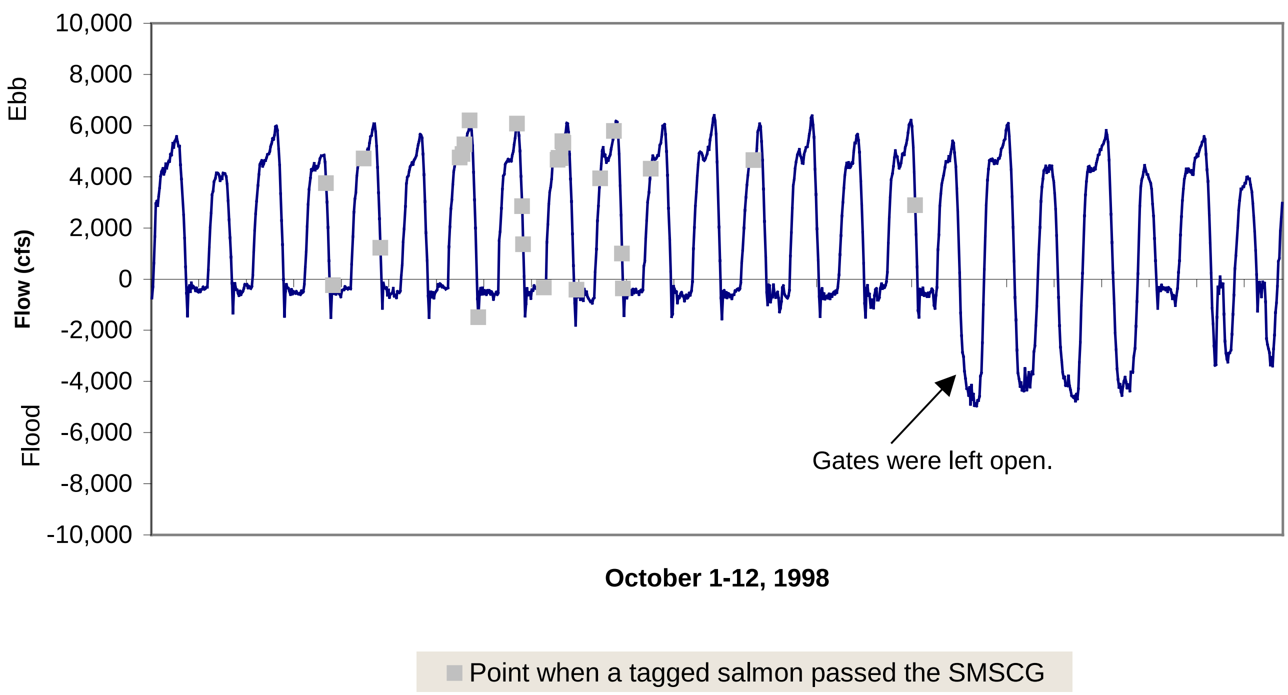


**Figure 5. Flow at SMSCG (UVM) vs. Time of Salmon Passage**
**Everything out of the water - 1998**

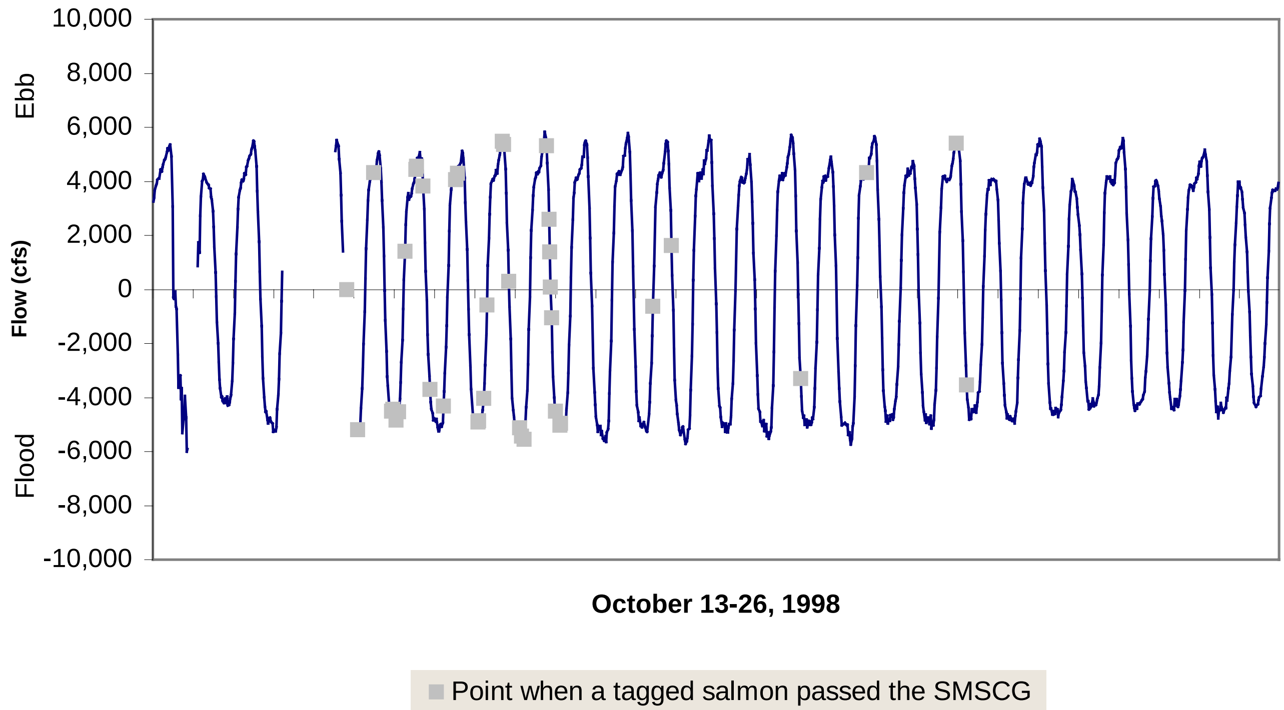



**Figure 6. Flow at SMSCG (UVM) vs. Time of Salmon Passage**
**Modified flashboards - 1998**

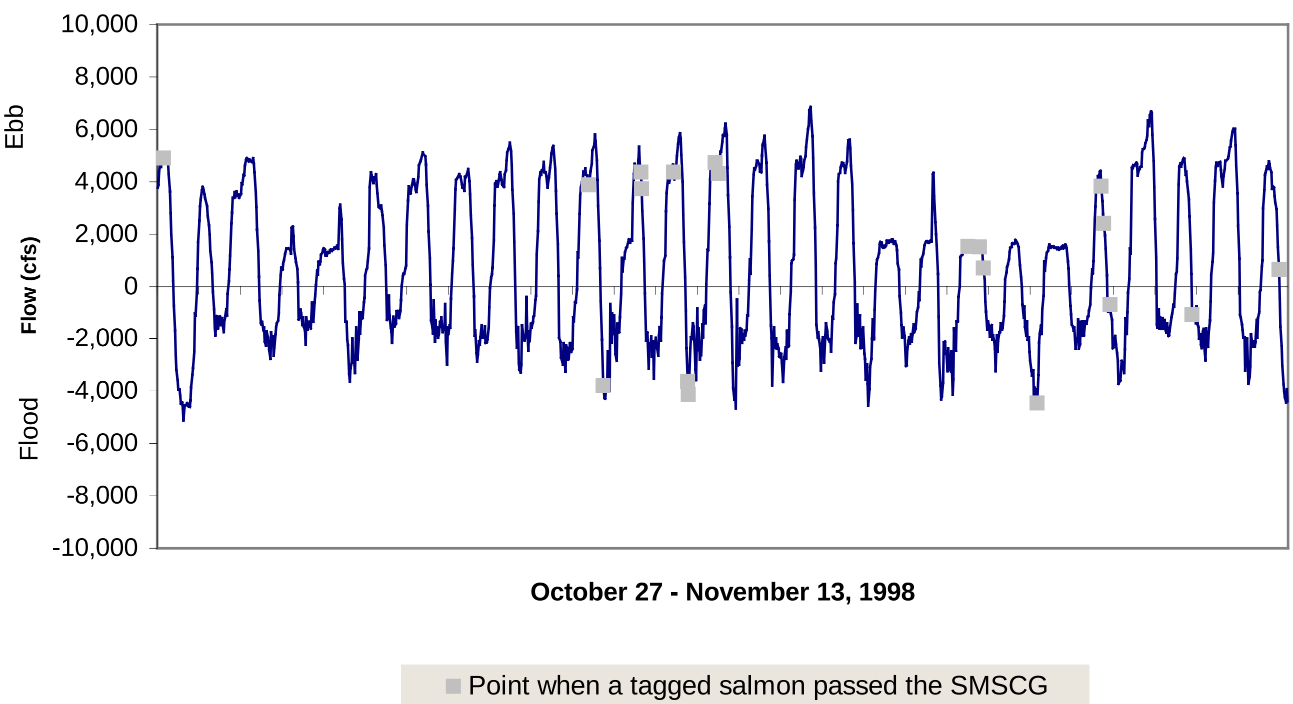


**Figure 7. Flow at SMSCG (UVM) vs. Time of Salmon Passage**
**Modified flashboards- 1999**

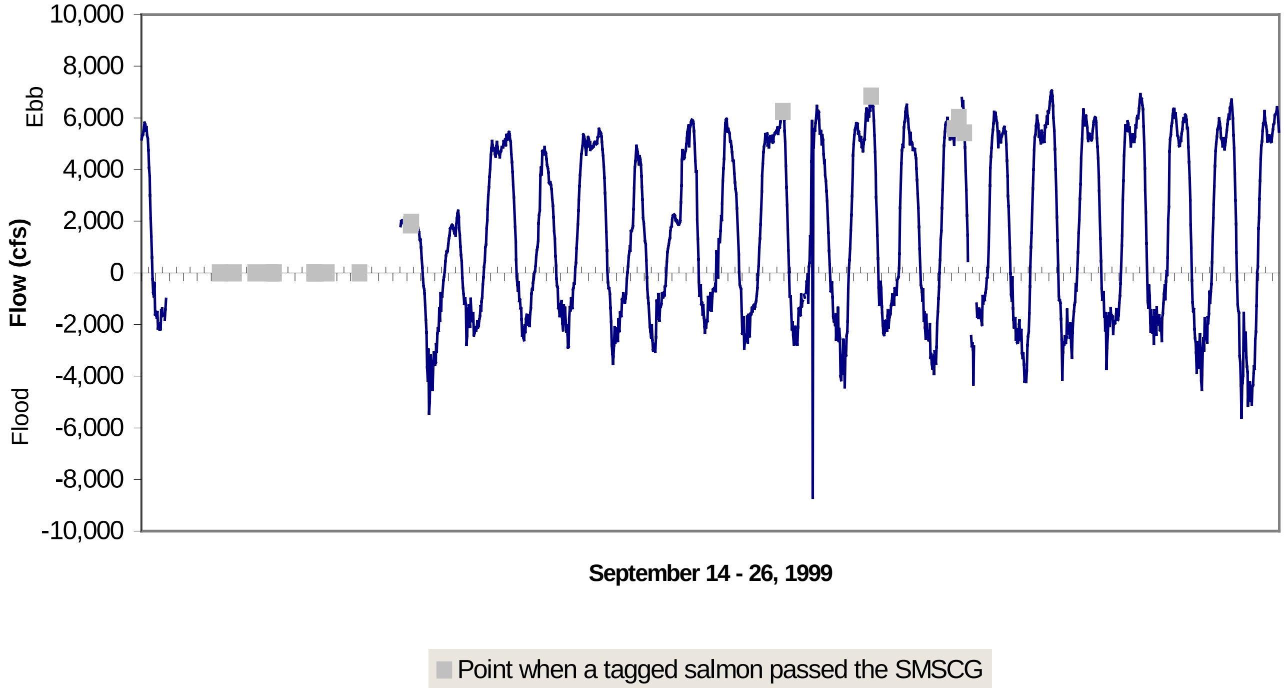



**Figure 8. Flow at SMSCG (UVM) vs. Time of Salmon Passage**
**Full bore operation - 1999**

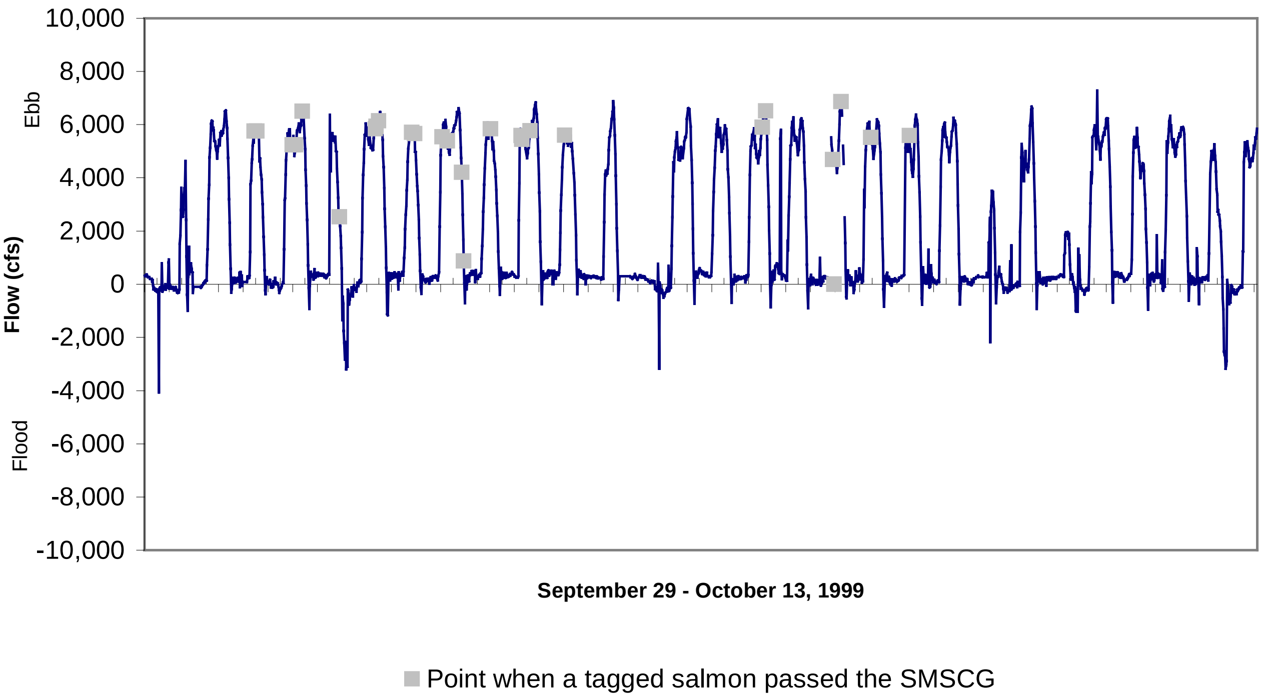
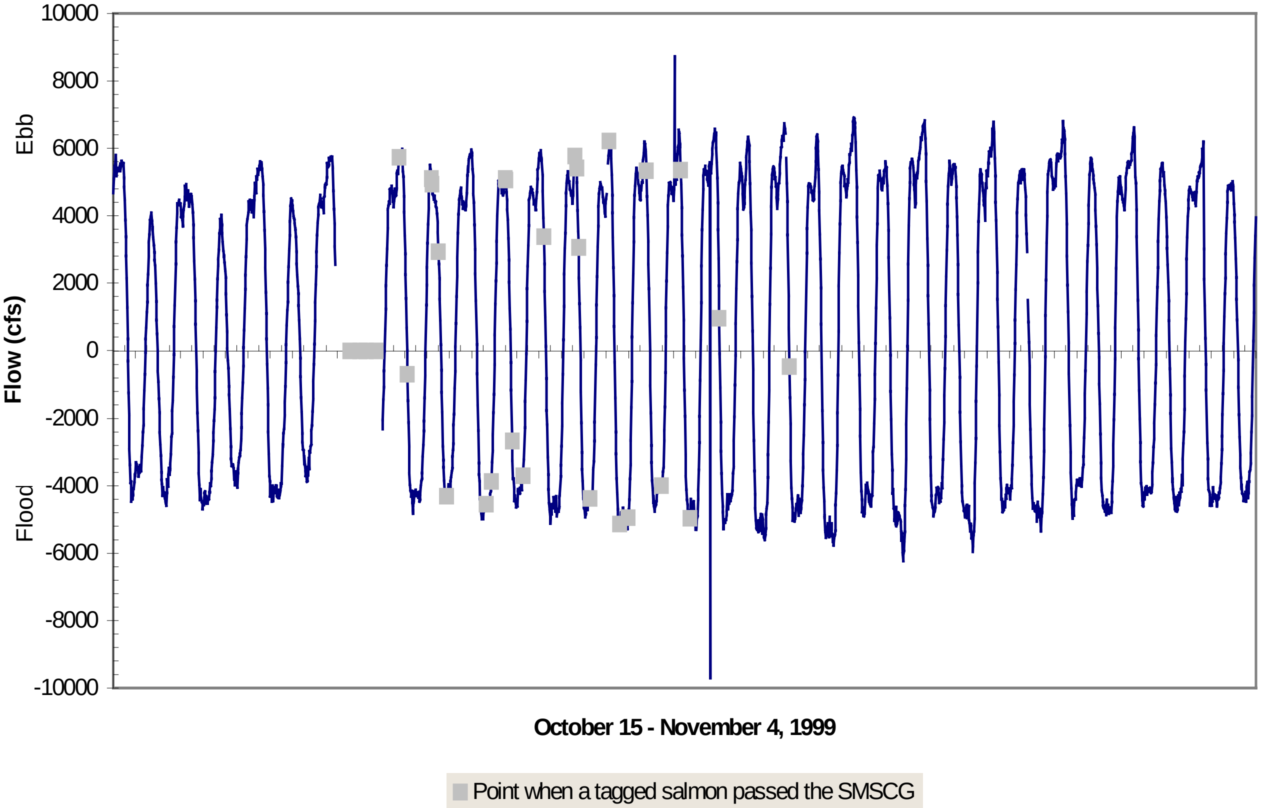


**Figure 9. Flow at SMSCG (UVM) vs. Time of Salmon Passage**
**Everything out of the water - 1999**



Hypothesis: There is no relationship between moon phase at time of passage and passage number.

Methods: Moon phase (full, last quarter, new, or first quarter) at the time of passage was determined for each fish of each study year and phase. For analysis purposes, a phase of the moon included approximately 3.5 days before and after. Thus, each phase lasts approximately 7 days.

In addition, a visual inspection of the passage and release dates and numbers related to moon phase was made (Figures 10 - 13). This visual inspection allows the continuous nature of moon phases to be observed.

Results: No relationship could be made between phase of the moon and passage number because the data is unable to sufficiently test the stated hypothesis. However, observation of the relationship between fish release moon phase and passage moon phase shows the tendency for more fish to pass close to their release phase.

Figures 10 - 13 and Table 28 below show a bias of passage to time of release. That is, more fish pass closer to the release time than far away from the release time. Thus, time at passage is related to release time, and moon phase at passage is biased by time of release. Most fish releases occurred during the first and last moons. Most passage occurred during full and new moons. Overall, 55% of the fish of all four study years were released and passed during first quarter and full moons, and 45% were released and passed during the last quarter and new moons.

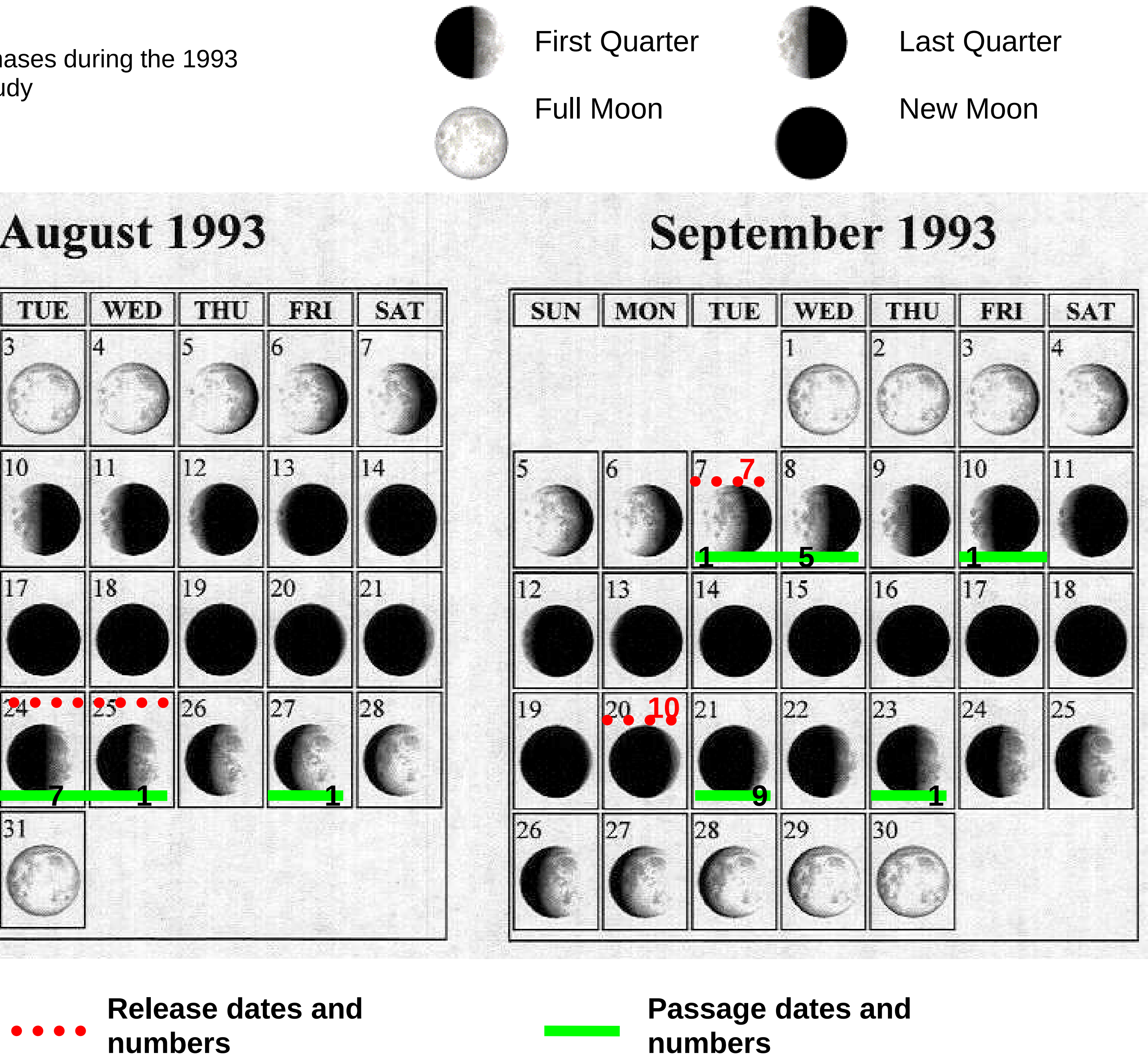
Table 28. Moon phase and numbers of fish at release and passage times.

| 1993, 94, 98, and 99 Phase of moon | # Released[1] | % of total released | # Passed | % of total passed |
|---|---|---|---|---|
| new | 23 | 10 | 46 | 21 |
| first | 89 | 40 | 56 | 25 |
| full | 32 | 15 | 65 | 30 |
| last | 76 | 35 | 53 | 24 |

[1]Only those fish that eventually passed are accounted for in the release numbers shown here.

Discussion: The study was not intended to relate moon phase with fish passage. Thus, no care was taken to release fish consistently throughout a moon phase or at equivalent times between phases. For this reason, the design of the study itself precludes meaningful analysis of the stated hypothesis and only some qualitative observations could be made.

Figure 10. Moon phases during the 1993 SMSCG salmon study



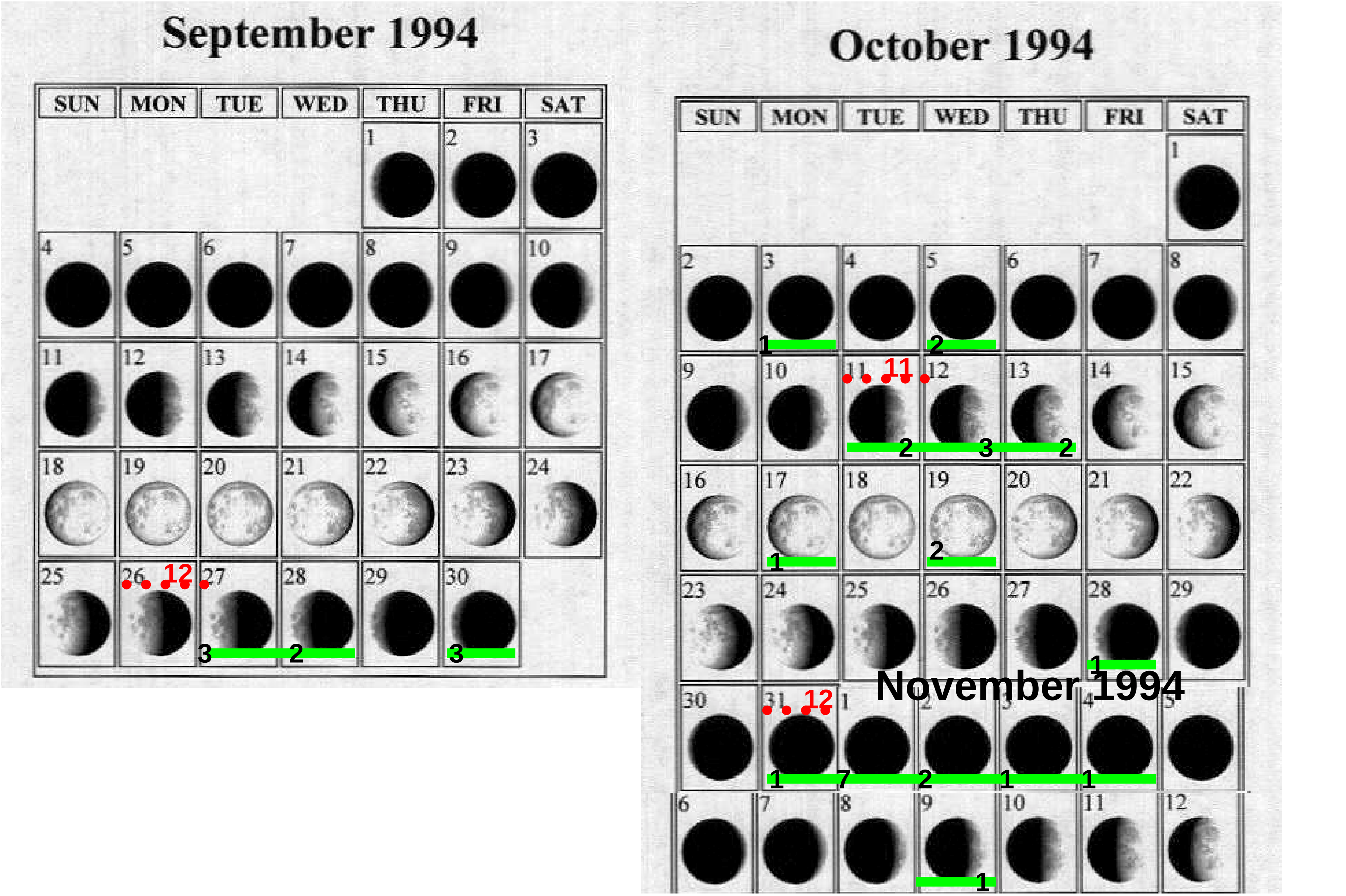



Figure 11. Moon phases during the1994 SMSCG salmon study

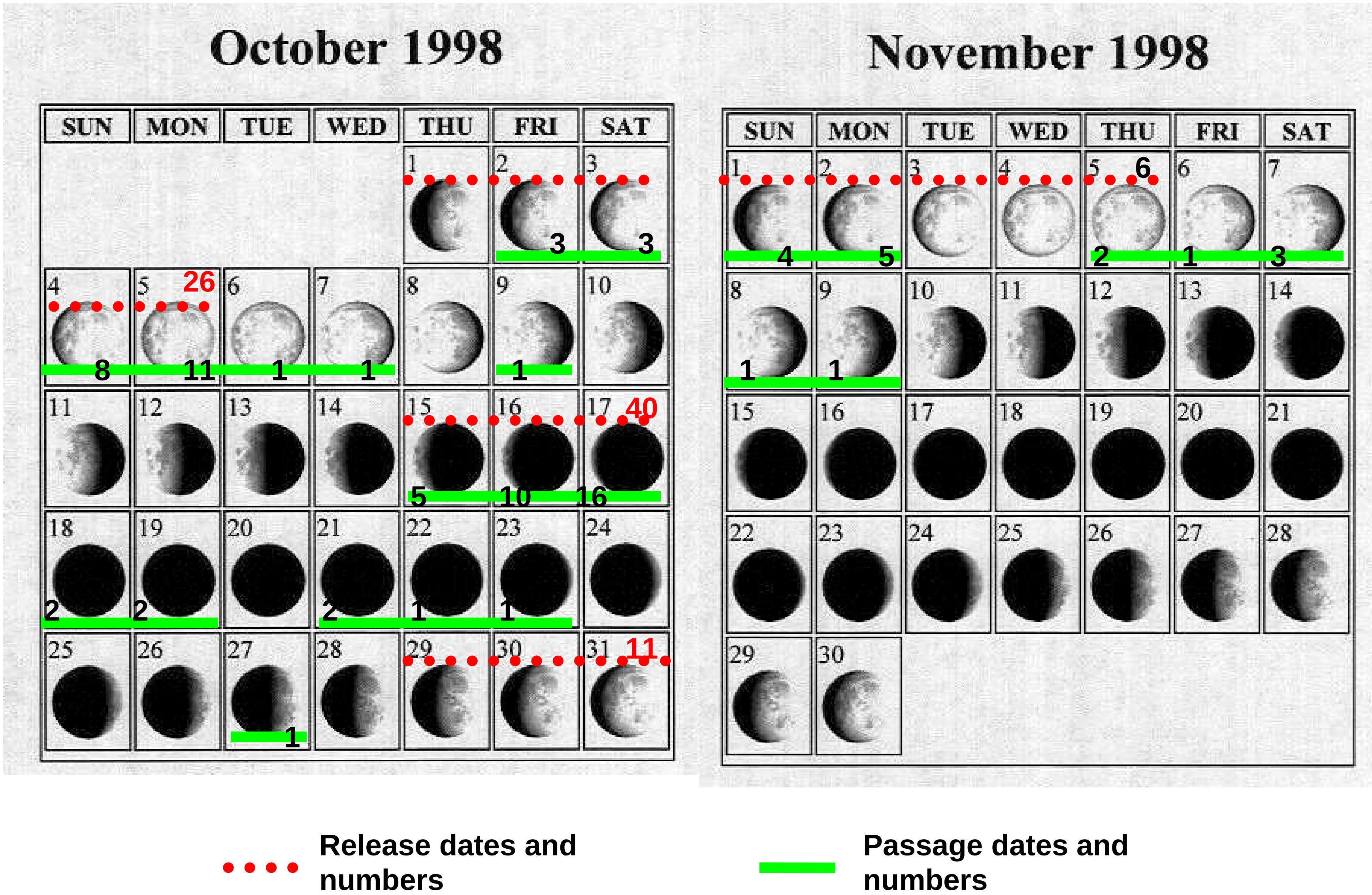



Figure 12.  Moon phases during the 1998 SMSCG salmon study

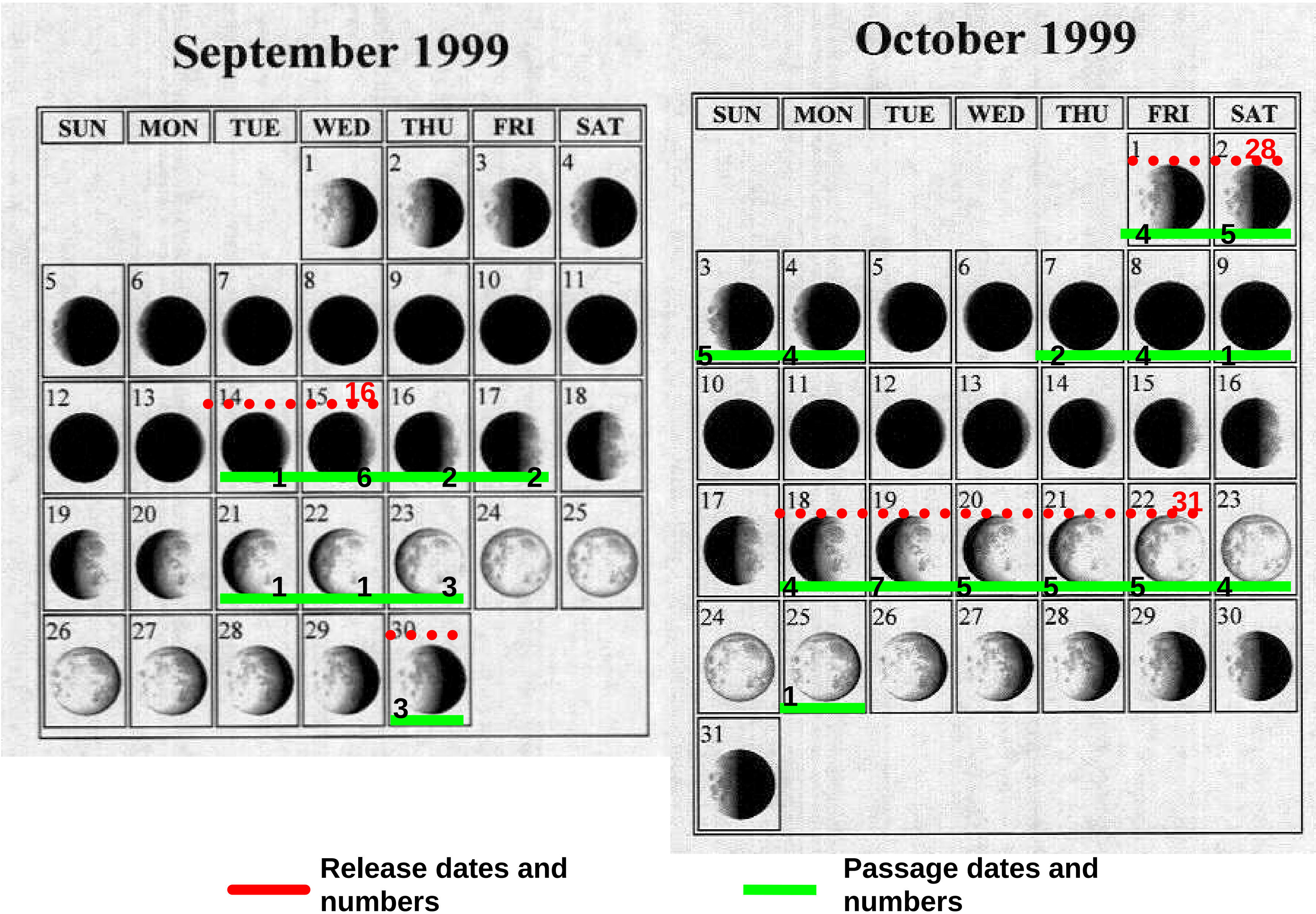



Figure 13. Moon phases during the 1999 SMSCG salmon study

Hypothesis: There is no relationship between moon phase at time of release and passage duration (time from release to passage).

Methods: A visual analysis of moon phase during the time of fish release correlated with average fish passage duration was made. For each year and phase of study, the moon phase during release was associated with the average number of hours from release to passage of all fish released during that phase.

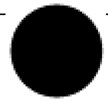
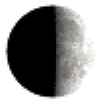
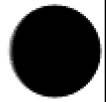
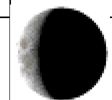
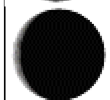
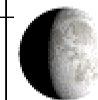
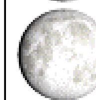
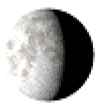
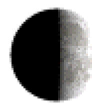
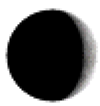
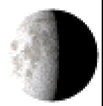
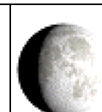
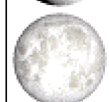
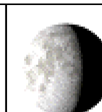
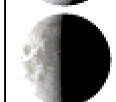
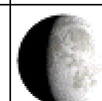
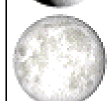
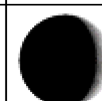
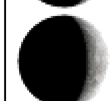
Results: Table 29 shows moon phase, passage duration, and range of duration times for each year and study phase. No relationship could be made between phase of the moon and passage duration.

In 1998, similar moon phase conditions (nearly full and waxing) existed during the fully operational phase and the modified flashboard phase. However, these two phases resulted in average fish passage duration times of 26 and 100 hours, respectively. In 1999, dissimilar moon phase conditions resulted in similar average passage duration times during the fully operational and modified flashboards phases. Upon visual inspection of the data, no pattern to further analyze these data emerged.

Discussion: Associating the moon phase with passage duration was confounded by the wide range of average passage duration times, from 1 hour to approximately 10 days. The moon phases applied for this analysis last approximately one week. The attempt to associate passage duration times of over 3 days to a moon phase of one week seems inappropriate.

Table 29. Moon Phase during Salmon Release

D = Average duration to passage in hours. Accounts for total time from release to passage.
R = Range of duration times.

| | 1993 | | | | 1994 | | | | 1998 | | | | 1999 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | date | moon | D | R | date | moon | D | R | date | moon | D | R | date | moon | D | R |
| **I<br>No flshbrds<br>Gates open<br>Lock closed** | 8/18<br>to<br>8/24 |  | 12 | 1-71 | 10/31 |  | 58 | 8-207 | 10/15<br>to<br>10/17 |  | 30 | 1.2-181 | 10/18<br>to<br>10/22 |  | 42 | 2.8-126.4 |
| **II<br>Full flshbrds<br>Gates open<br>Lock operating** | 9/7 |  | 23 | 4-65 | 10/11 |  | 61 | 8-199 | | | | | | | | |
| **III<br>Full flshbrds<br>Gates operating<br>Lock operating** | 9/20 |  | 25 | 7-69 | 9/26 |  | 88 | 10-213 | 10/1<br>to<br>10/5 |  | 26 | 2.1-101.8 | 9/30<br>to<br>10/2 |  | 70 | 3.3-190.8 |
| **Modified flshbrds** | | | | | | | | | 10/29<br>to<br>11/5 |  | 100 | 8-234.8 | 9/14<br>to<br>9/15 |  | 76 | 2.3-210.4 |

Hypothesis: There is no relationship between tide type at time of release and total passage time (time from release to passage).

Methods: For the purpose of this analysis, it is assumed that moon phase corresponds directly to tide type. Thus, a full moon corresponds to a spring tide and a quarter moon with a neap. This analysis is analogous with the analysis of moon phase vs. total passage time. *Please see the moon phase vs. total passage time analysis description for more information.*

Hypothesis: There is no relationship between tide type at time of release and total passage number.

Methods: For the purpose of this analysis, it is assumed that moon phase corresponds directly to tide type. Thus, a full moon corresponds to a spring tide and a quarter moon with a neap. This analysis is analogous with the analysis of moon phase vs. passage number. *Please see the moon phase vs. passage number analysis description for more information.*

Hypothesis: There is a salinity gradient in Montezuma Slough.  This gradient is affected by operation of the SMSCG.

Methods:  DWR's DSM1 model was used to simulate wet and dry season salinity conditions along Montezuma Slough.  Simulations were made for a single spring/neap cycle during February and July 1992.  These time periods were selected to demonstrate the range of expected salinity gradient in Montezuma Slough under varying hydrologic conditions. Salinity values were output at 1000 foot intervals along the Slough.  In order to assess the effect of the SMSCG on the salinity gradient, both time periods were simulated with and without SMSCG operations.

Results:  Figures 14 & 15 show the salinity versus distance for February 1 - 14, 1992 and July 1 - 14, 1992.  The gradient shown goes upstream along Montezuma Slough from the point of release just downstream of the SMSCG to the confluence with the Sacramento River.  In general, salinities are greater in July when Delta outflow is less than in February.

The wet season (February 1992) salinity under operational SMSCG conditions varies from approximately 2.9 ppt in Montezuma Slough at the point of release to 2.5 ppt upstream at the confluence of the Sacramento River with the Slough. Under non-operational gates status, salinity varies from 5.3 to 2.4 ppt.  The shape of the salinity curve within the Slough from the point of release to the confluence with the Sacramento River varies greatly between the two SMSCG operational conditions in February.

The dry season (July 1992) salinity under operational SMSCG conditions varies from approximately to 6.7 to 5.6 ppt and from 7.1 to 5.6 ppt under non-operational conditions.  When the SMSCG are operating, the salinity gradient flattens out immediately downstream of the gates and then maintains a similarly sloped gradient as that experienced under non-operational gates status.

Discussion: The SMSCG would normally be operated in February and not in July. Since the salmon flow study was conducted during the relatively dry months of August through October, the salinity gradient in Montezuma Slough would likely be more similar to that experienced in July 1992. The salinity gradient appears to be affected more by SMSCG operations under wetter conditions.

The results indicate a salinity gradient exists along Montezuma Slough and is greatly affected by operation of the SMSCG.  However, the effect of differing gradients on adult salmon movement is not known.

Figure 14. Salinity Gradient of average salinity Feb 1 - 14, 1992
along Montezuma Slough from point of release
to confluence with Sac. R.

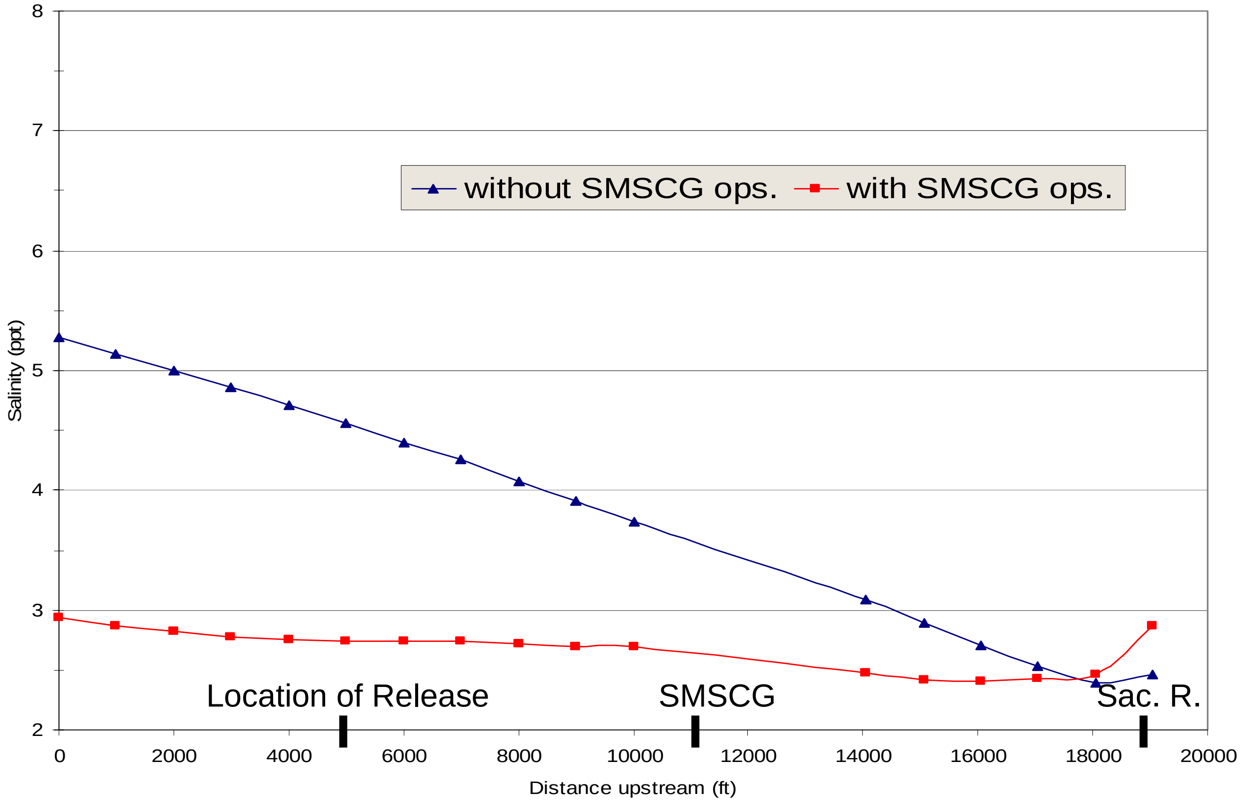
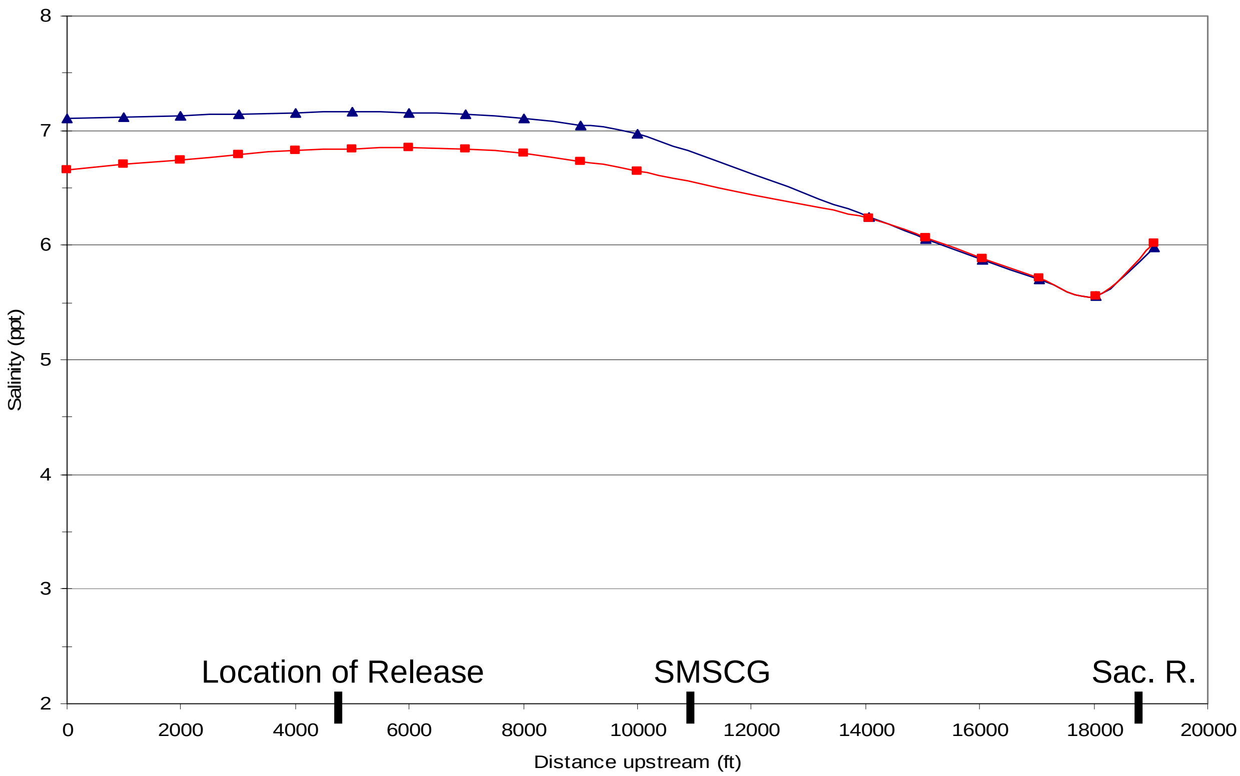



Figure 15. Salinity gradient of average salinity July 1 - 14, 1992
along Montezuma Slough from point of release
to confluence with Sac. R.



Null Hypothesis: The water temperature during each of the three study phases in 1999 at S-64 was within the accepted temperature range for chinook salmon migration[123]. The three study phases are defined as:

- modified flashboards installed and gates operated – Sept 14 to Sept 26,1999 (Phase I),
- regular flashboards installed gates operated – Sept 29 to Oct 13, 1999 (Phase II), and
- everything out of the water – Oct 15 to Nov 4, 1999 (Phase III).

Alternative Hypothesis: The water temperature during each of the three study phases in 1999 at S-64 was not within the accepted temperature range for Fall run chinook salmon.

Methods: Obtained data files for the DWR S64 Permanent Monitoring Station. Readings were collected by the monitoring station every 15mins. Readings were taken 1 meter below the water surface. Percent of time temperatures exceeded 20.0°C was calculated by counting the number of times temperatures were above 20.0°C X 15mins for each time/total time of the Phase.

Results:

Table 30. Temperature information at S-64 during the 1999 SMSCG salmon study

| | Phase I | Phase II | Phase III |
|---|---|---|---|
| Average | 18.8 | 19.5 | 17.4 |
| Minimum | 17.6 | 18.1 | 16.1 |
| Maximum | 20.1 | 21.9 | 19.8 |
| Std Deviation | 0.5 | 0.7 | 0.7 |

Discussion:

The temperatures during Phase I and Phase II exceeded the accepted maximum temperature range for Fall chinook salmon migration by 0.2% and 20.1% of the time respectively in 1999 at S-64. Since previous research indicates chinook salmon are able to sustain temperatures of up to 26.2°C[2] for short periods of time, it is believed that these temperatures which did not exceed 21.9°C did not hinder the salmon passage at the gates. Phase III was within the accepted temperature range the whole time, therefore, salmon did not experience a temperature barrier (Table 31 & 32).

---

[1] Accepted maximum temperature for salmon in this study was established at 20°C.

[2] Lower lethal temperature = 0.8°C and Upper lethal temperature = 26.2°C (Bjornn and Reiser 1991).

[3] Spawning migration temperatures for anadromous Fall run chinook salmon ranges from 10.6°C to 19.4°C (Bell 1986).

**Table 31. Montezuma Slough 1999 water quality at S-64**

**Data collected by Hydrolab DataSonde 3 at S-64**

| Readings Hourly | **DO** | **DO** | **Depth** | **Batt** |
|---|---|---|---|---|
| | %Sat | mg/l | feet | volts |
| **Modified Flashboards** | | | | |
| **Phase I** Data only available from Sept 17 to Sept 26, 99 | | | | |
| Avg. | 93.4 | 8.50 | 3.6 | 13.5 |
| Min. | 90.2 | 8.20 | 2.2 | 12.7 |
| Max. | 101.0 | 8.90 | 7.1 | 14.7 |
| SD | 1.9 | 0.14 | 1.1 | 0.5 |
| **Regular Flashboards** | | | | |
| **Phase II Sept 29, 99 to Oct 13, 99** | | | | |
| Avg. | 92.0 | 8.26 | 2.7 | 13.6 |
| Min. | 84.5 | 7.60 | 2.1 | 12.8 |
| Max. | 100.4 | 8.91 | 3.3 | 15.4 |
| SD | 2.9 | 0.24 | 0.2 | 0.5 |
| **Everything Out** | | | | |
| **Phase III Oct 15, 99 to Nov 3, 99 at 1300** | | | | |
| Avg. | 76.1 | 7.10 | 2.5 | 13.2 |
| Min. | 57.4 | **5.40** | 1.7 | 12.1 |
| Max. | 89.4 | 8.45 | 3.0 | 14.5 |
| SD | 6.6 | 0.59 | 0.3 | 0.6 |

D.O. below 6.0 mg/l occurs 6.60% of the time.

First fish was tagged on Sept. 14, 99, therefore, computations are based on tagging start date.

**S-64 Permanent Monitoring Station Data**

| Readings every 15 mins. | Temperature (C) | EC (uS/cm) | EC (ppm at SLSUS12) Sea Water = 34ppt |
|---|---|---|---|
| **Sept 14, 99 to Sept 26, 99** | | | |
| Avg | 18.8 | 5655 | 3.39 |
| Min | 17.6 | 3809 | 2.21 |
| Max | **20.1** | 8239 | 5.03 |
| Std Deviation | 0.5 | 917 | |

Temperature above 20.0C occurs .2% of the time.

| | | | |
|---|---|---|---|
| **Sept 29, 99 to Oct 13, 99** | | | |
| Avg | 19.5 | 5952 | 3.58 |
| Min | 18.1 | 3724 | 2.16 |
| Max | **21.9** | 10309 | 6.35 |
| Std Deviation | 0.7 | 1410 | |

Temperature above 20.0C occurs 20.1% of the time.

| | | | |
|---|---|---|---|
| **Oct 15, 99 to Nov 4, 99** | | | |
| Avg. | 17.4 | 9099 | 5.58 |
| Min. | 16.1 | 6265 | 3.77 |
| Max. | 19.8 | 12515 | 7.75 |
| Std Deviation | 0.7 | 1842 | |

**Table 32. Montezuma Slough 1999 water quality at S-71**

**Data collected continuous by YSI 6600 at S-71**

| Reading every 30 mins. | **DO** sat % | **DO** mg/L | **Depth** feet | **Battery** volts |
|---|---|---|---|---|
| **Modified Flashboards** | | | | |
| **Phase I** | **Sept 14, 99 to Sept 26, 99** | | | |
| No Data Available for this Time Period | | | | |
| **Regular Flashboards** | | | | |
| **Phase II** | **Sept 29, 99 to Oct 13, 99** | | | |
| No Data Available for this Time Period | | | | |
| **Everything Out** | | | | |
| **Phase III** | **Oct 21, 99 to Nov 2, 99 at 1332 hrs** | | | |
| Avg. | 87.6 | 8.14 | 3.072 | 12.7 |
| Min. | 60.7 | **5.63** | 2.365 | 12.3 |
| Max. | 99.7 | 9.22 | 3.308 | 13.3 |
| SD | 10.1 | 0.92 | 0.121 | 0.2 |

D.O. below 6.0 mg/l occurs 3.8% of the time.

**S-71 Permanent Monitoring Station Data**

| Readings every 15 mins. | Temperature (C) | EC (uS/cm) | EC (ppm at SLSUS12) Sea Water = 34ppt |
|---|---|---|---|
| | **Sept 14, 99 to Sept 26, 99** | | |
| Avg. | 18.7 | 5470 | 3.27 |
| Min. | 17.6 | 2948 | 1.67 |
| Max. | **20.2** | 8810 | 5.39 |
| Std Deviation | 0.5 | 995 | 0.42 |

Temperature equal or above 20.0C occurs 0.08% of the time.

| | | | |
|---|---|---|---|
| | **Sept 29, 99 to Oct 13, 99** | | |
| Avg. | 19.4 | 5977 | 3.59 |
| Min. | 18.1 | 2365 | 1.29 |
| Max. | **21.0** | 10017 | 6.16 |
| Std Deviation | 0.5 | 1263 | 0.59 |

Temperature equal or above 20.0C occurs 11.3% of the time.

| | | | |
|---|---|---|---|
| | **Oct 15, 99 to Nov 4, 99** | | |
| Avg. | 17.3 | 9461 | 5.81 |
| Min. | 16.1 | 5051 | 3.00 |
| Max. | 19.6 | 13032 | 8.08 |
| Std Deviation | 0.7 | 1458 | 0.72 |

Null Hypothesis: Dissolved oxygen during each of the three study phases in 1999 at S-64 did not drop below 6.0mg/L[123]. The three study phases are defined as:

- modified flashboards installed and gates operated – Sept 17, 99 to Sept 26, 99 (Phase I),
- regular flashboards installed gates operated – Sept 29, 99 to Oct 13, 99 (Phase II), and
- everything out of the water – Oct 15, 99 to Nov 3, 99 at 1300 (Phase III).

Test Hypothesis: Dissolved oxygen during each of the three study phases in 1999 at S-64 did drop below 6.0mg/L[123].

Methods: Obtained data files for the S64 Hydrolab DataSonde 3. Readings were recorded hourly. Measurements were collected 1 meter below the water surface. Percent of time dissolved oxygen dropped below 6.0mg/l was calculated by counting the number of times dissolved oxygen dropped below 6.0mg/l X 60mins for each time/total minutes of the Phase.

Results:

Table 33. Dissolved oxygen at S-64 during the 1999 SMSCG salmon study

| | Phase I | Phase II | Phase III |
|---|---|---|---|
| Average | 8.50 | 8.26 | 7.10 |
| Minimum | 8.20 | 7.60 | 5.40 |
| Maximum | 8.90 | 8.91 | 8.45 |
| Std Deviation | 0.14 | 0.24 | 0.59 |

Discussion:

Dissolved oxygen levels for Phase I and II did not drop below 6.0mg/L for any amount of time, therefore, it is deduced that there was no DO sag barrier to hinder migration through the gates. Phase III experience a slight sag in DO levels but it was only for 6.60% of the time with levels no lower than 5.40mg/l. According to research, temporary sags slightly below 6.0mg/L are not major inhibitors for migration (Table 31 & 32).

[1] For this study minimum DO levels were set at 6.0mg/L.

[2] Hallock et al. 1970 showed at migrating adults exhibit an avoidance response to DO levels below 4.5mg/l, but indicated that migration resumed when DO levels increased to 5mg/L.

[3] Davis (1975) estimated that salmonids would suffer no impairment if DO concentrations remained near 8mg/L and determined that DO deprivation would begin at approximately 6mg/L.

Question: What was the water quality measured during profiling runs in 1999?

Methods: Three water quality profile runs were done during the 1999 SMSCG salmon study. One run was performed during each study phase. The dates of the profile runs were:

- 9/24/99 in the modified flashboard and gates operating phase (modified flashboard phase),
- 10/4/99 in the regular flashboard and gates operating phase (full bore phase), and
- 10/20/99 in the everything out of the water phase (fully open phase).

All measurements were collected using a YSI 6600 multiparameter measurement and logging system with an atmospheric vent cable. The system was calibrated immediately before each run and checked afterwards for drift. Calibration for dissolved oxygen was accomplished using the barometric-compensated moisture-saturated air technique. A digital barometer was used for deriving the DO calibration input value. Depth was calibrated by "zeroing" out against atmospheric pressure. Temperature was checked/calibrated against a mercury-in-glass laboratory thermometer certified against an NIST primary reference thermometer. Specific electrical conductivity was calibrated against standard solutions prepared by DWR's Bryte laboratory. Standard solutions were selected for use based on expected SEC levels in Montezuma Slough.

Water quality profile measurements were taken at the stations shown on Figure 16. Profile runs were accomplished by boat with measurements taken as close as possible to the center of the channel at 20 stations. Profiles at each station began about 0.1 meters below the surface and ended about 0.3 meters from the channel bottom. Measurements were taken during the following time periods:

| | |
|---|---|
| 9/24/99 | 12:42-15:41 hours |
| 10/4/99 | 9:24 - 12:23 hours |
| 10/20/99 | 11:58 - 14:26 hours |

All profile runs started at the upstream end of Montezuma Slough and proceeded downstream toward the confluence with Nurse Slough (MSR1 toward MSR20).

Results:
Water quality conditions about 0.5 meter below the surface in Montezuma Slough during the 3 profiling runs are shown in Figures 17-19. Water temperatures ranged from 17.4-20.0 °C. Specific conductance level ranged from 3.5-9.8 mS/cm. Dissolved oxygen concentrations ranged from 6.5-9.4 mg/l.

Water quality about 0.3 meters from the bottom in Montezuma Slough on the 3 profiling dates are also shown in Figures 20-22. At 0.3 meters from the bottom of the channel, water temperature through the slough ranged from 17.4-19.4 °C. Specific conductance levels ranged from 3.5-10.9 mS/cm. Dissolved oxygen concentrations ranged from 6.3-9.0 mg/l.

Low dissolved oxygen readings, around 6 mg/l, occurred from stations MSR 7-10. These stations were in the vicinity of the release point for tagged salmon and the location of the continuous monitoring stations at S-64 (both water quality and sonic tag receiver).

There was minimal dissolved oxygen stratification at stations MSR 7-10. Dissolved oxygen concentrations from the surface to the channel bottom were within 0.2 mg/l at these sites (Figures 23-25). The difference between surface (about 1 meter) and bottom dissolved oxygen concentrations at all stations within Montezuma Slough was no more than 0.4 mg/l during all 3 profiling runs.

Discussion:
Water quality profiling results confirm the occurrence of dissolved oxygen around 6.0 mg/l during the phase when everything is out of the water in 1999. Continuous D.O. monitoring at S-64 recorded D.O.'s less than 6.0 mg/l on 10/20/99-10/23/99. The D.O.'s less than 6.0 mg/l ranged from 5.4-5.9 mg/l and temperatures during the same time periods ranged from 17.0-17.5 °C. (See the 1999 dissolved oxygen write up on page 56.)

There are six water fowl club drains in the stretch of Montezuma Slough from the SMSCG to the confluence with Nurse Slough (Raquel 2000). The diameter of the drains range from 16 – 36 inches. It is possible that the low D.O.'s were the result of water released from water fowl clubs in the area, a phytoplankton die off or some other cause. Field personnel noticed what appeared to be at least one drain discharging during the study (Floyd, personal communication; see Notes). However, the water quality portion of the study was not designed to determine the cause of low D.O.'s in the slough. A more intensive study would be needed to address this issue.

The study design required that capturing of salmon stop when D.O.'s measured 6.0 mg/l or less. The Technical Team compared times when tagged salmon were released and times when D.O.'s measured less than 6.0 mg/l using the continuous water quality measurements collected at S-64 and S-71 and the profile measurement runs. The comparison showed that no salmon were released (and none were captured) when D.O.'s measured less than 6.0 mg/l.

Hallock and others (1970) reported that D.O.'s less than 5.0 mg/l blocked salmon movement in the Sacramento-San Joaquin estuary. Water quality profiling and continuous D.O. monitoring did not measure D.O.'s less than 5.0 mg/l during the 1999 study. In addition, based on the profiling done in 1999, the D.O in the water column appears to be well mixed 1 meter below the surface to the bottom of the channel in Montezuma slough. This makes it unlikely that there were depths unsuitable for fish passage when D.O.'s reached 5.4 mg/l one meter below the surface at S-64.

Citation:
Hallock R., Elwell R., and D. Fry, Jr. 1970. Migrations of adult king salmon, *Oncorhynchus tshawytscha*, in the San Joaquin Delta. Department of Fish and Game. Fish Bulletin 151: 63.

Raquel P. 2000. Department of Fish and Game Fish Screens and Fish Passage Project Diversion Database. Sacramento: Department of Fish and Game, Inland Fisheries Division.

Notes:

Floyd M. (Department of Water Resources). 27 December 2000. Conversation with author.

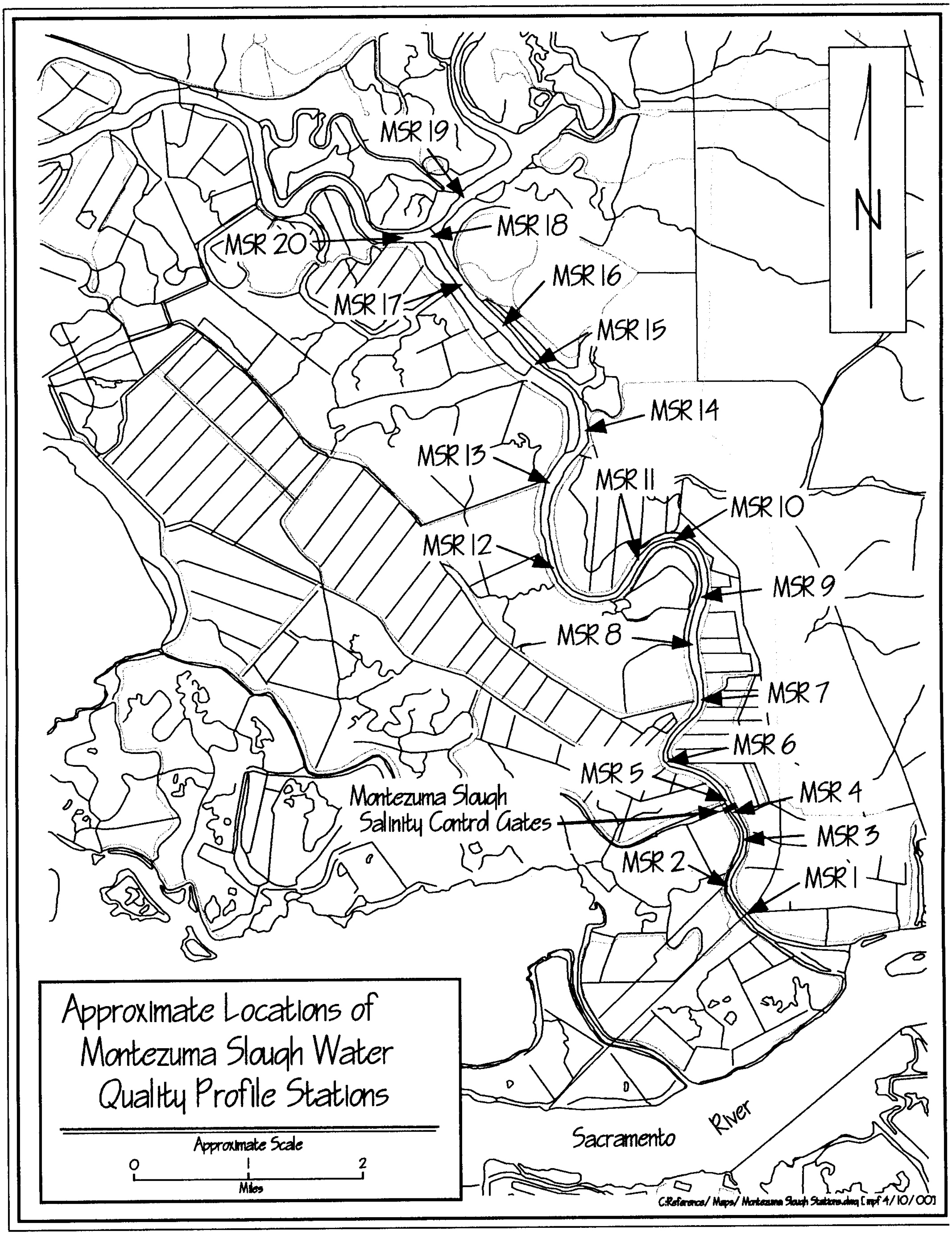



Figure 16. Approximate locations of water quality profiling stations in Montezuma Slough during the 1999 SMSCG salmon study

**Figure 17. Water quality about 0.5 meter* below the surface in Montezuma Slough on 9/24/99 (modified flashboards)**

(*Measurements taken at a depth closest to 0.5 meter were used. Depths in this graph ranged from 0.3-0.5 meters.)

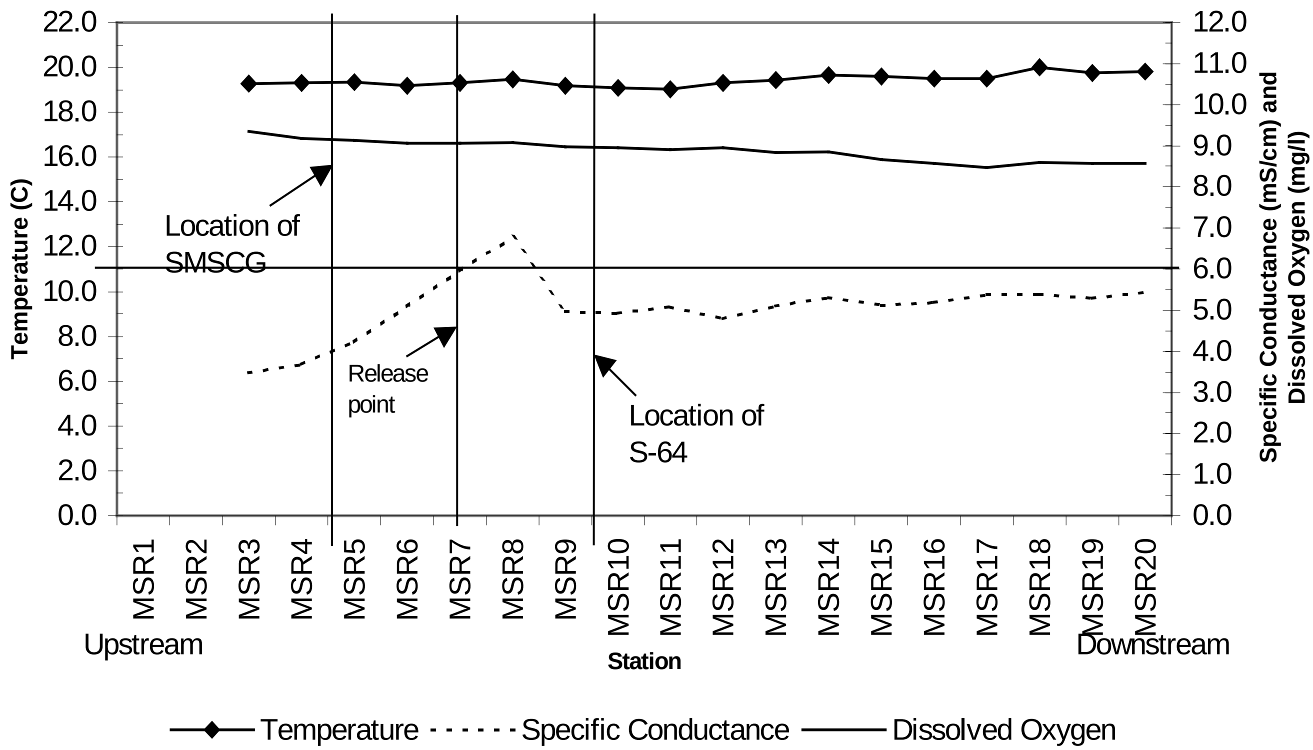



**Figure 18. Water quality about 0.5 meter* below the surface in Montezuma Slough on 10/04/99 (full bore phase)**

(*Measurements taken at a depth closest to 0.5 meter were used. Depths used for this graph ranged from 0.1-1.1 m.)

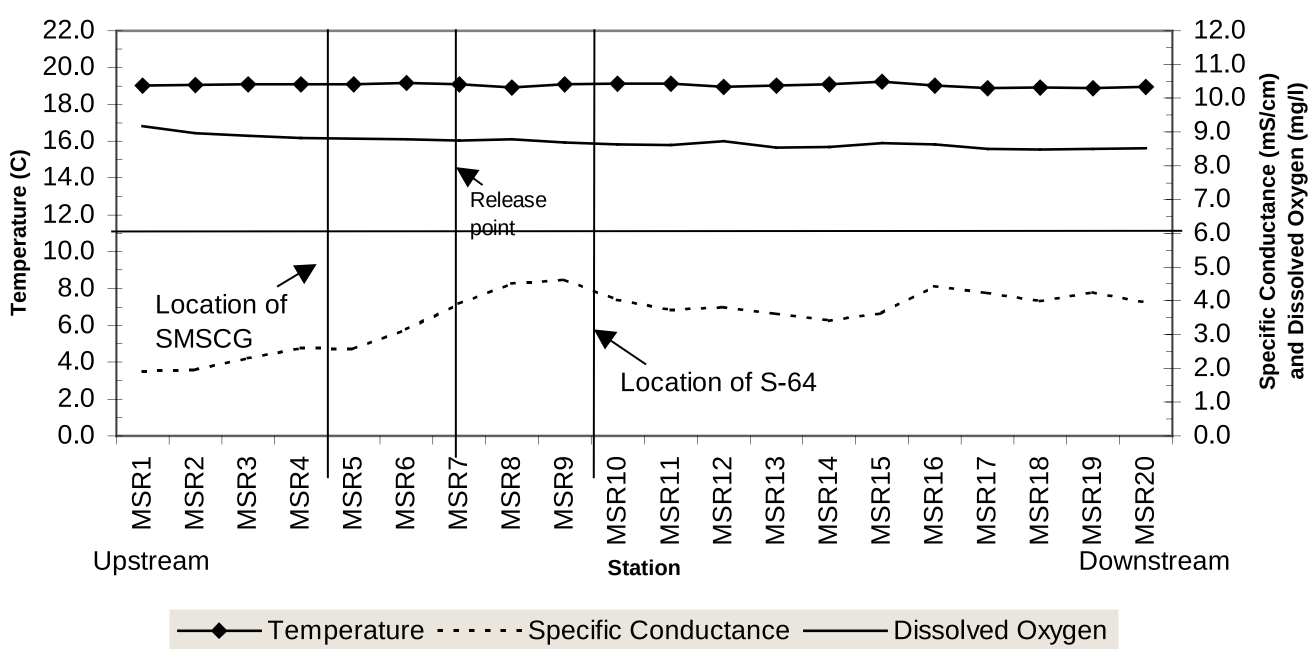


**Figure 19. Water quality 0.5 meter* from surface in Montezuma Slough on 10/20/99 (fully open phase)**

(*Measurements taken at a depth closest to 0.5 meter were used. Depths in this graph ranged from 0.1-0.6 meters.)

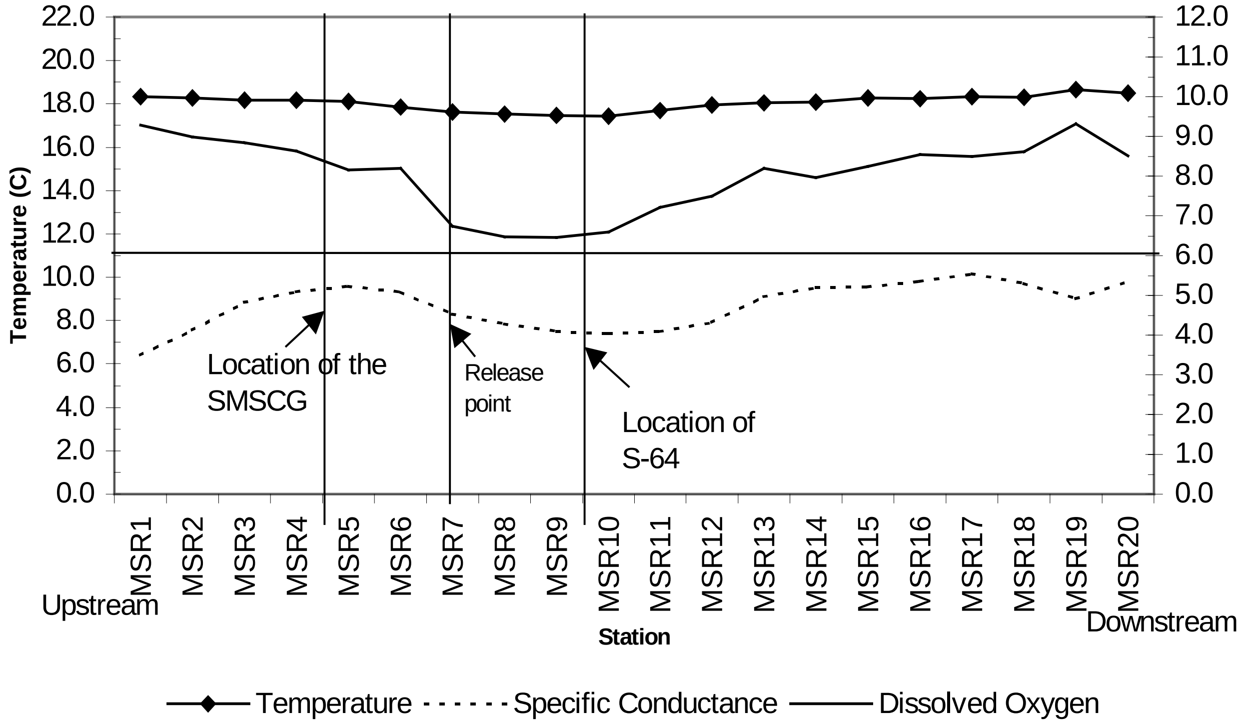



**Figure 20. Water quality about 0.3 meters from the bottom in Montezuma Slough on 9/24/99 (modified flashboard phase)**

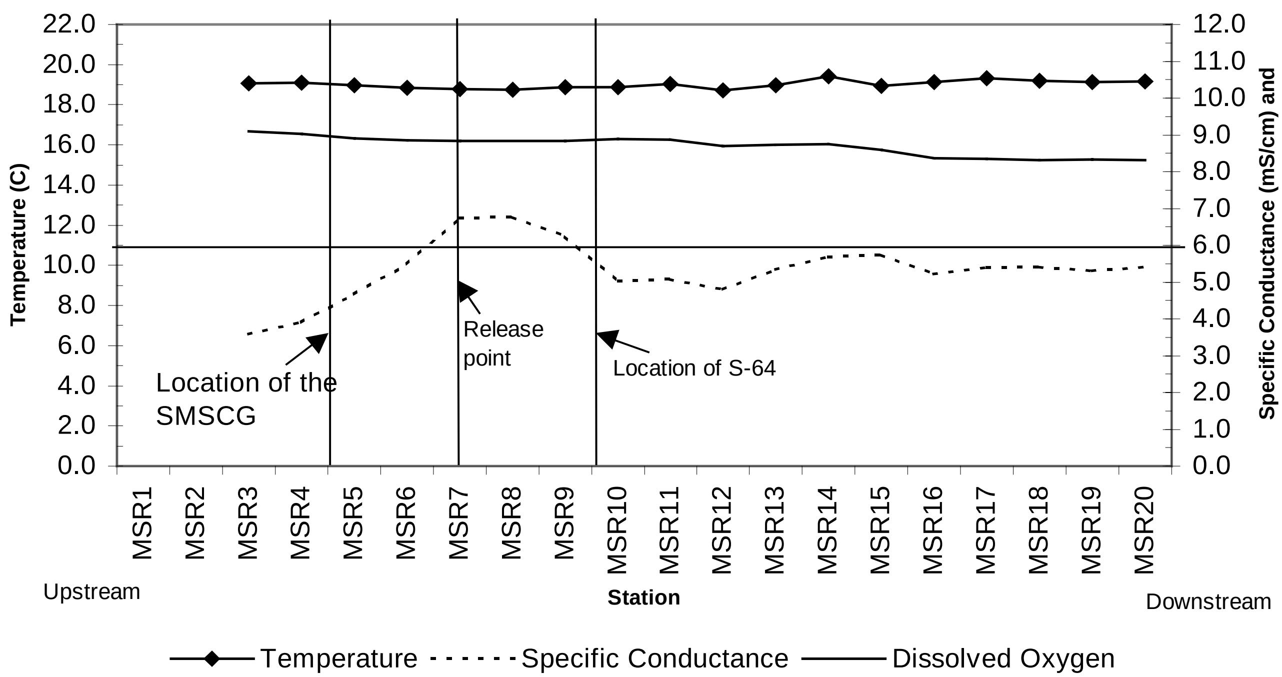


**Figure 21. Water quality about 0.3 meters from the bottom in Montezuma Slough on 10/04/99 (full bore phase)**

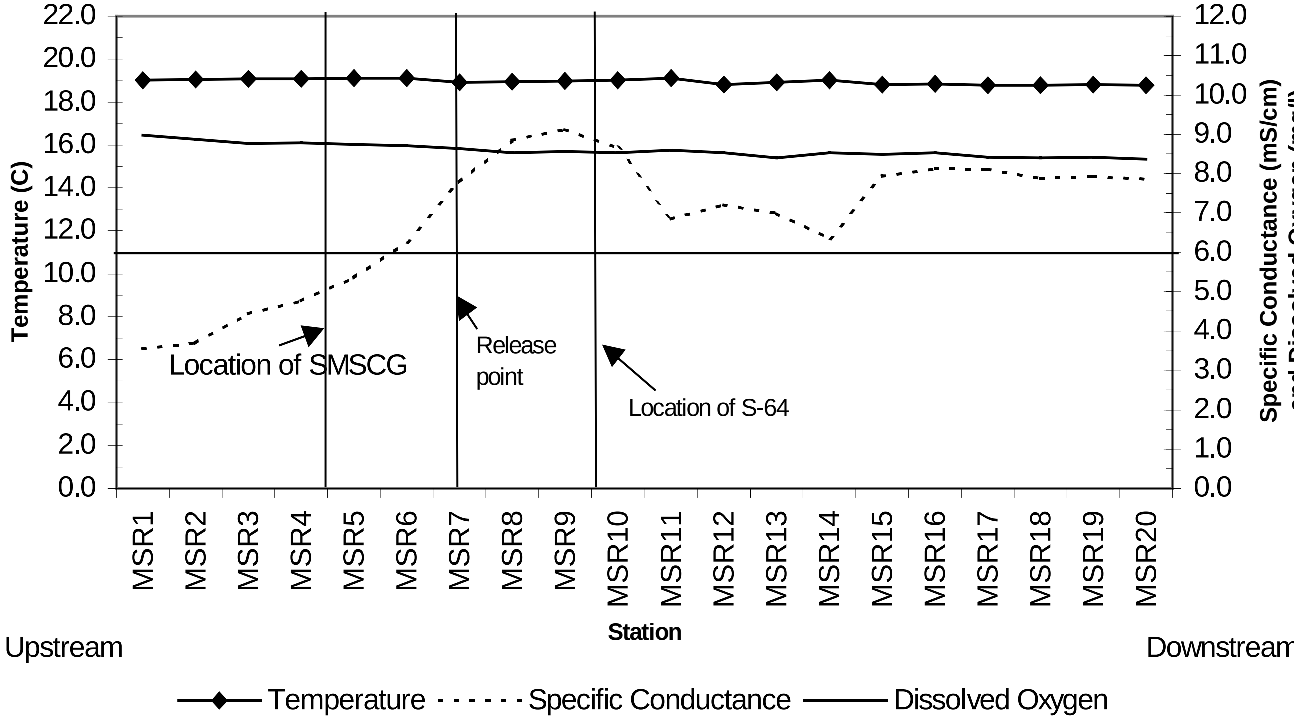



**Figure 22. Water quality about 0.3 meters from the bottom in Montezuma Slough on 10/20/99 (fully open phase)**

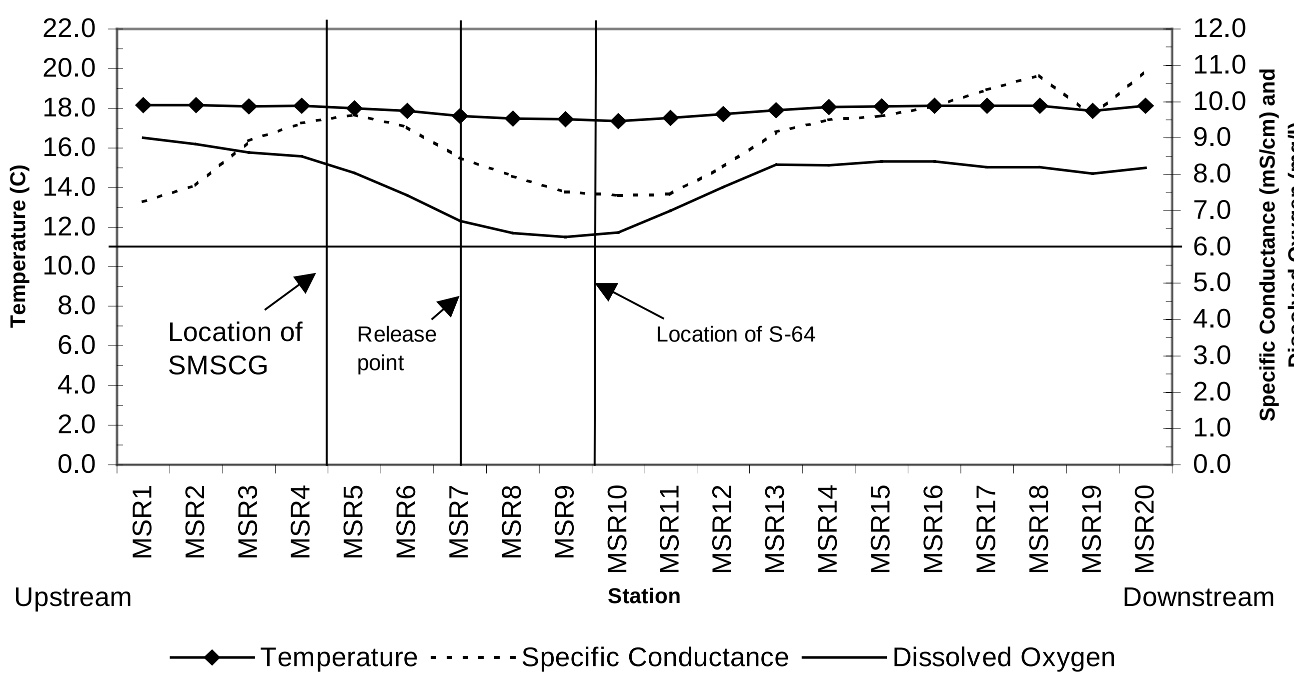


**Figure 23. Dissolved oxygen at stations MSR7-10 on 9/24/99 (modified flashboards phase)**

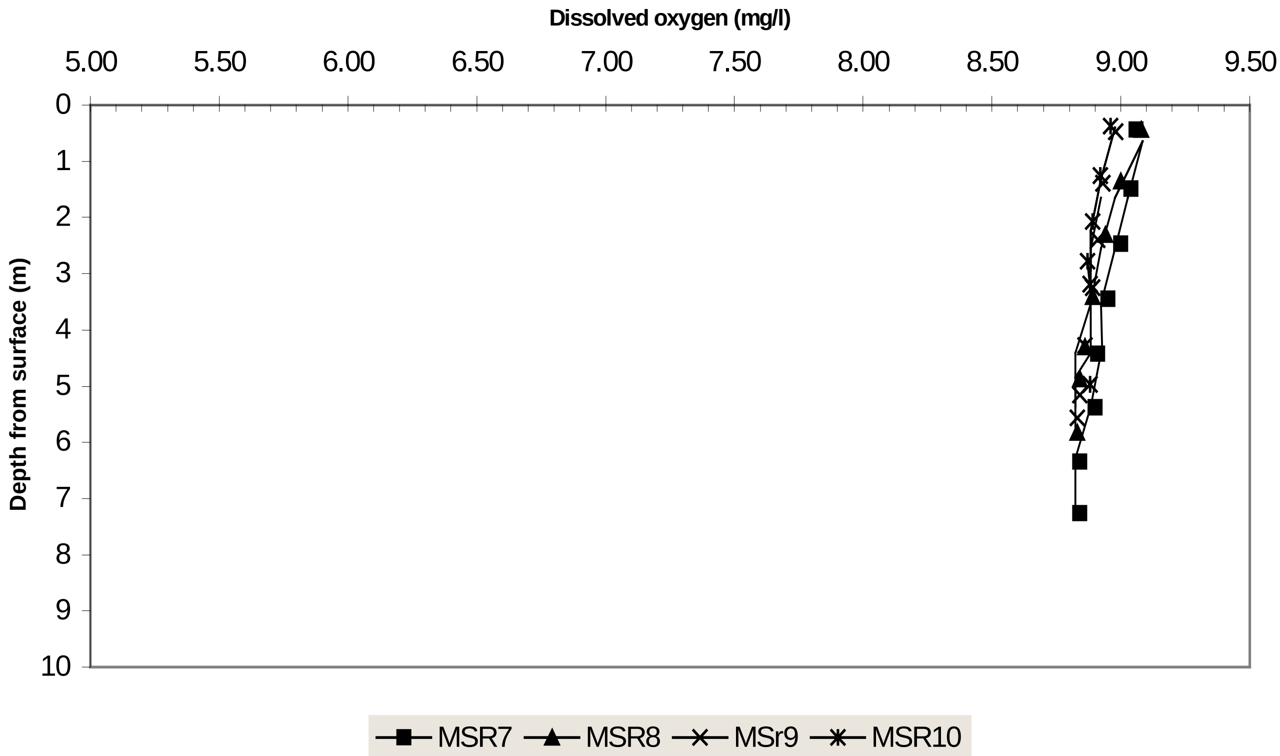



**Figure 24. Dissolved oxygen at Stations MSR7-10 on 10/4/99 (full bore phase)**

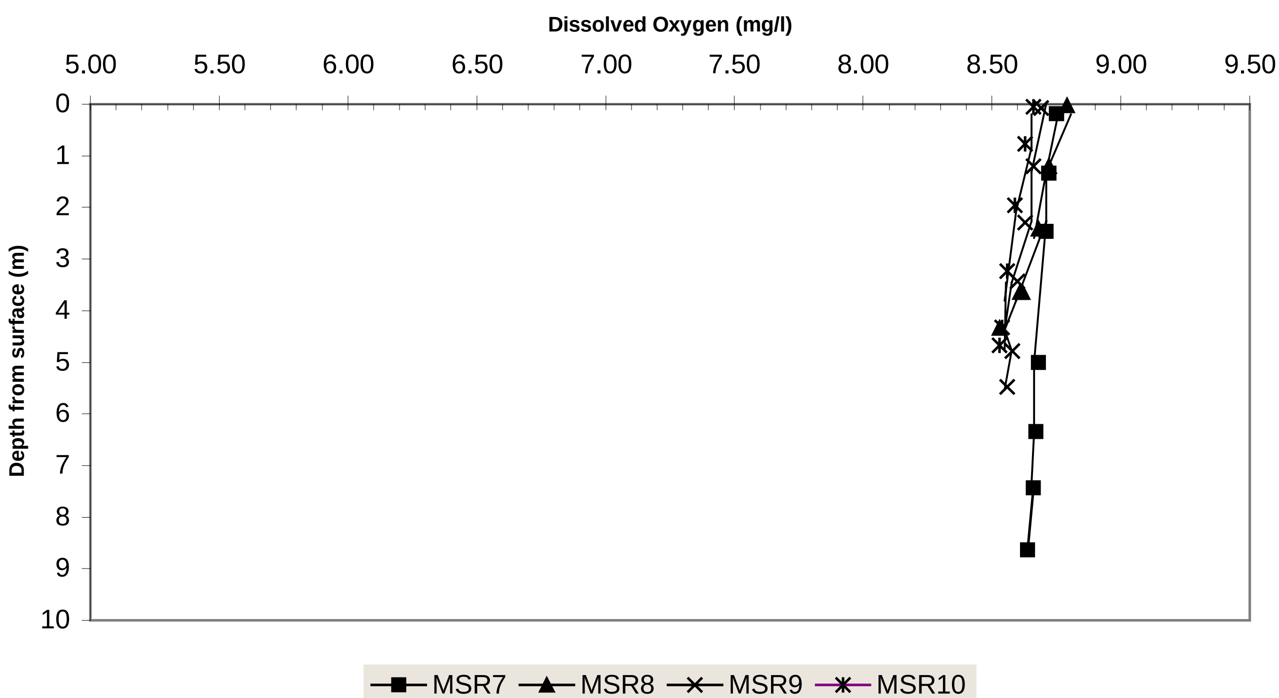
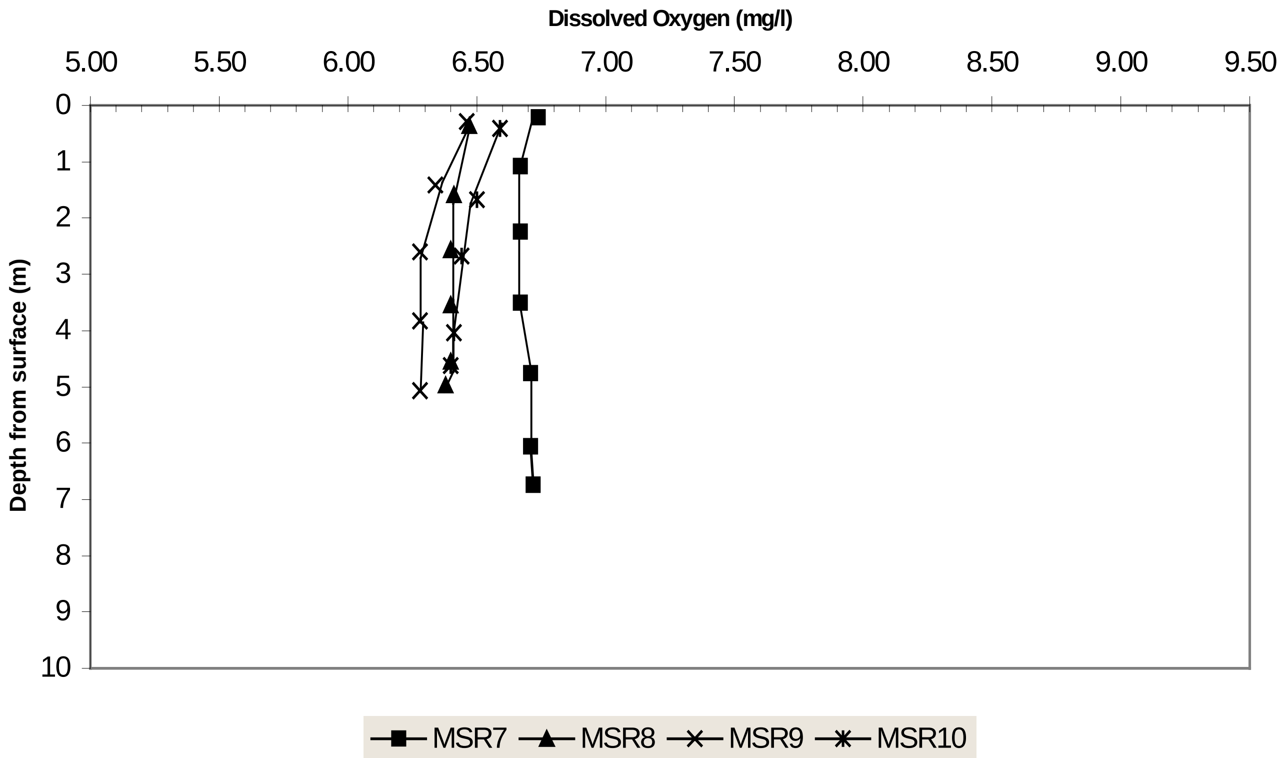


**Figure 25. Dissolved oxygen at stations MSR7-10 on 10/20/99 (fully open phase)**



Null Hypothesis:  Dissolved oxygen values less than 6.0 mg/l affected salmon movement near S-64 and Station 9.

Alternative hypothesis:  Dissolved oxygen values less than 6.0 mg/l did not affect salmon movement near S-64 and Station 9.

Methods:
Hourly dissolved oxygen data collected at Station S-64 were overlaid with salmon occurrence data from Station 9 from October 19-23, 1999.  Station S-64 and Station 9 are the same location.  I plotted data from October 19-23 because D.O. values $\leq$ 6.0 mg/l were recorded within that time period.  I assumed that dissolved oxygen values represented conditions through out each hour period so that I could overlay it with salmon occurrence data (at less than one minute intervals).  The horizontal distance of each bar represents the length of time the fish was recorded in the vicinity of Station 9.  There is no relationship between each horizontal bar and the y-axis.

Results:
The results of the dissolved oxygen with salmon occurrence plots are shown in Figure 26.  Dissolved oxygen less than 6.0 mg/l occurred 7 times during the fully open phase in 1999.  Twenty-two different salmon were recorded at Station 9 during the times when D.O.'s were less than 6.0 mg/l.  Salmon were separated into 5 different detection categories as shown in Table 34.

Table 34.  Kinds of salmon occurrences during dissolved oxygen readings <6.0mg/l at Station 9 in 1999.

| Detection categories | # of salmon |
| --- | --- |
| Salmon detected before D.O. < 6.0mg/l and stayed beyond the time when D.O's were > 6.0 mg/l (eg. Tag 198 on 10/21) | 2 |
| Salmon detected at Station 9 before D.O. < 6.0mg/l and left when D.O's were still < 6.0 mg/l (eg. Tag 172 on 10/20) | 11 |
| Salmon showed up during low D.O. event and left before D.O.'s were > 6.0 mg/l (eg. Tag 203 on 10/22) | 12 |
| Salmon showed up, left and returned all during a period when D.O.'s were < 6.0 mg/l (eg. Tag 137 on 10/20) | 5 |
| Salmon showed up and stayed at Station 9 during low DO event (eg. Tag 193 on 10/20) | 15 |

Tag numbers indicate the order that fish were caught, tagged and released. The release dates of each of the salmon recorded at Station 9 from 10/19-10/23/99 are shown in Table 35.

Table 35. Release dates and passage of salmon detected at Station 9 during days when D.O.'s were < 6.0 mg/l

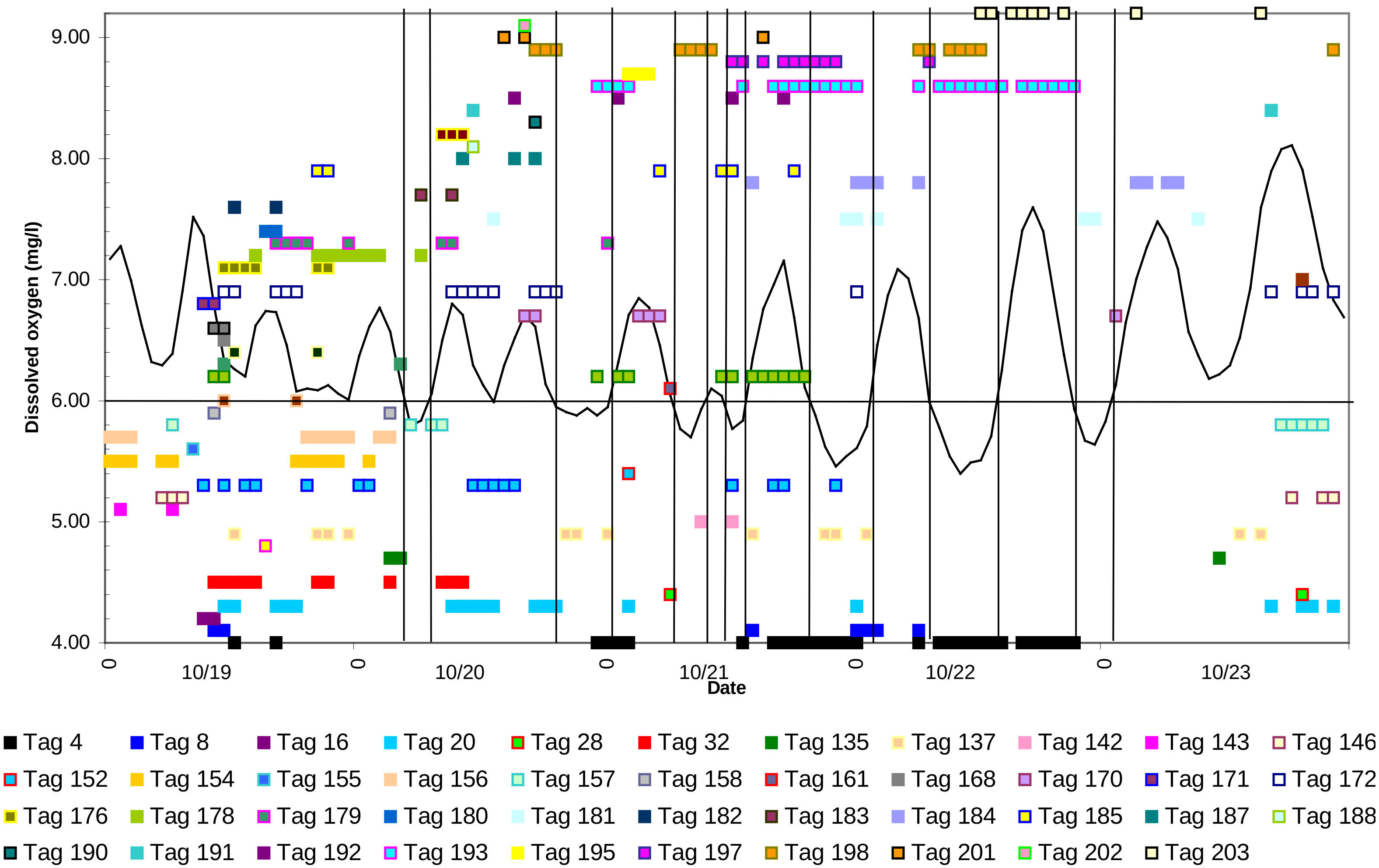
| Tag # | Release Date | Passage in fully open phase | Tag # | Release Date | Passage in fully open phase | Tag # | Release Date | Passage in fully open phase |
|---|---|---|---|---|---|---|---|---|
| 4 | 9/14/99 | pass | 158 | 10/19/99 | pass | 183 | 10/19/99 | no pass |
| 8 | 9/14/99 | pass | 159 | 10/19/99 | no pass | 184 | 10/19/99 | pass |
| 16 | 9/14/99 | pass | 161 | 10/19/99 | pass | 185 | 10/19/99 | pass |
| 20 | 9/14/99 | pass | 162 | 10/19/99 | pass | 187 | 10/20/99 | pass |
| 28 | 9/14/99 | pass | 163 | 10/19/99 | no pass | 188 | 10/20/99 | no pass |
| 32 | 9/15/99 | pass | 164 | 10/19/99 | no pass | 189 | 10/20/99 | no pass |
| 135 | 10/18/99 | no pass | 168 | 10/19/99 | no pass | 190 | 10/20/99 | pass |
| 136 | 10/18/99 | pass | 169 | 10/19/99 | no pass | 191 | 10/20/99 | no pass |
| 137 | 10/18/99 | no pass | 170 | 10/19/99 | no pass | 192 | 10/20/99 | pass |
| 142 | 10/18/99 | no pass | 171 | 10/19/99 | no pass | 193 | 10/20/99 | no pass |
| 143 | 10/18/99 | no pass | 172 | 10/19/99 | pass | 195 | 10/20/99 | pass |
| 146 | 10/18/99 | pass | 174 | 10/19/99 | pass | 197 | 10/20/99 | no pass |
| 147 | 10/18/99 | pass | 176 | 10/19/99 | no pass | 198 | 10/20/99 | pass |
| 152 | 10/18/99 | pass | 178 | 10/19/99 | no pass | 201 | 10/20/99 | no pass |
| 154 | 10/18/99 | pass | 179 | 10/19/99 | no pass | 202 | 10/20/99 | pass |
| 155 | 10/18/99 | pass | 180 | 10/19/99 | pass | 203 | 10/22/99 | pass |
| 156 | 10/18/99 | no pass | 181 | 10/19/99 | no pass | | | |
| 157 | 10/18/99 | pass | 182 | 10/19/99 | no pass | | | |

Note: 9/14 and 9/15/99 are from the modified flashboard phase. 10/18 - 10/22/99 are from the fully open phase.

Discussion:
There did not seem to be a clear pattern of fish occurrence at Station 9 during time periods when D.O.'s were less than 6.0 mg/l. Eighty-eight percent of the fish that were picked up by Station 9 from 10/19-10/23 were tagged and released from 10/18-10/20. The remaining 12% were fish from Phase 1 (modified flashboard phase).

Evaluating the effects of dissolved oxygen on salmon behavior was confounded by time. The study phase began on 10/18 and the period of low dissolved oxygen measurements occurred within the first six days of the phase. Fifty-six percent of the salmon (30 fish) detected at Station 9 from 10/19-10/23 passed the SMSCG during this phase. Of the 30 fish that passed, all but 2 passed by 10/23. The remaining 46% did not pass the gates before the study ended on 11/3. Based on this visual inspection, fish movement at Station 9 did not seem to be affected by D.O.'s between 5.0 mg/l and 6.0 mg/l.

**Figure 20. Dissolved oxygen and salmon presence at S-64 from 10/19/99-10/23/99 (Horizontal bars, i.e. fish presence, have no relationship to y-axis.)**



Null hypothesis: The total time the gates were open between the full bore/regular flashboard and modified flashboard phases was the same in 1998.

Alternative hypothesis: The total time the gates were open in the full bore/regular flashboard phase was different from the total time the gates were open in the modified flashboard phase in 1998.

Methods: I used the site glass data from October 1-12, 1998 and from October 27-November 10, 1998 to calculate the amount of time the gates were open during the full bore operation phase and during the modified flashboard phase, respectively. Open gates were defined as times when the gates readings were at 20. I used a Chi-Square test ($\alpha$=0.05) to test two things:

- whether the amount of time each of the three gates was open was different within a phase, and
- whether the amount of time each of the gates was open was different between phases.

Results:

Table 35. 1998 – Total time gates were open per study phase (hours)

| | Gate 1 | Gate 2 | Gate 3 | Comments |
|---|---|---|---|---|
| Full bore | 188 | 188 | 188 | Gates did not close on 10/10 |
| Modified flashboards | 99 | 101 | 101 | Gate 1 did not open for a 2 hour period on 11/4. Gates did not open at all on 11/6. |

The Chi-square test showed no difference in the total time gates were open between or within the full bore and modified flashboard phases in 1998.

Discussion:
The differences in passage times and passage numbers between the full bore and modified flashboard phases in 1998 were not affected by the differences in time that the gates were open.

Null hypothesis: The total time the gates were open between the full bore/regular flashboard and modified flashboard phases was the same in 1999.

Alternative hypothesis: The total time the gates were open in the full bore/regular flashboard phase was different from the total time the gates were open in the modified flashboard phase in 1999.

Methods: I used the site glass data from September 7-26, 1999 and from September 29-October 13, 1999 to calculate the amount of time the gates were open during the modified flashboard phase and during the full bore operation phase, respectively. Open gates were defined as times when the gates readings were at 20. I used a Chi-Square test ($\alpha$=0.05) to test two things:

- whether the amount of time each of the three gates was open was different within a phase, and
- whether the amount of time each of the gates was open was different between phases.

Results:

| Table 36. 1999 – Total time gates were open per study phase (hours) | | | | |
|---|---|---|---|---|
| | Gate 1 | Gate 2 | Gate 3 | Comments |
| Full bore | 150 | 154 | 150 | Gates 1 & 3 did not open on 10/6 for a four hour period. |
| Modified flashboards | 193 | 193 | 161 | Data gaps between 9/9-9/10 and 9/14-9/16. Gate 3 did not open from 9/17-9/20. |

The Chi-square test showed no difference in the total time gates were open between or within the full bore and modified flashboard phases in 1999.

Discussion:
The differences in passage times and passage numbers between the full bore and modified flashboard phases in 1999 were not affected by the differences in time that the gates were open.

Null hypothesis: The amount of blockage that occurred during the modified flashboard phase was the same as the amount in the full bore phase in 1998 and in 1999.

Alternative hypothesis: The amount of blockage that occurred during the modified flashboard phase was different from the amount in the full bore phase in 1998 and in 1999.

Methods for 1998 analysis:
A blockage occurs when a fish arrives at the gates for the first time and the gates are closed and the fish does not pass in the phase it was tagged (Edwards and others 1996). To determine if a fish was blocked I compared the first occurrence of a fish at Station 9 and/or 10 with the gate position at the same time. Station 9 and 10 were the 2 stations closest to the downstream side of the gates. First occurrence was determined by 3 consecutive detections at Station 9 and/or 10 in a 2 minute period. I used the fifteen minute site glass data to determine whether the gates were open (a reading of 20 ), closed (a reading of 0), or moving.

Methods for 1999 analysis:
The methods are the same as in 1998 except fish detections from Station 7 and/or 8 were used to determine when a fish first arrived at the gates. In 1999 Station 7 and 8 were the 2 stations closest to the downstream side of the gates.

Results:

Table 37. Blockage rates during the 1998 and 1999 SMSCG salmon studies

| | Modified Flashboards Phase | | Full Bore Phase | |
|---|---|---|---|---|
| | 1998 | 1999 | 1998 | 1999 |
| # arriving when closed | 34 | 17 | 17 | 10 |
| # arriving when open | 25 | 24 | 29 | 28 |
| # arriving when opening | 0 | 0 | 2 | 2 |
| # arriving when closing | 1 | 0 | 4 | 0 |
| Percentage Blocked within phase | 42% | 19% | 29% | 8% |

In 1998, 2 of the blocked fish tagged in the full bore phase passed in the subsequent fully open phase. Additionally, 3 of the blocked fish tagged in the full bore phase passed in the modified phase. One fish from the fully open phase passed in the modified phase rather than in the fully open phase when it was tagged.

In 1999, 2 of the blocked fish tagged in the modified flashboard phase passed in the subsequent full bore operation phase.

Discussion:
- Higher blockage rates occurred in 1998 than in 1999 regardless of phase.
- In both years higher blockage rates occurred in the modified flashboard phase.

- The higher blockage rates during the modified flashboard phases do not appear to be because the gates were open less time during those phases (see the Total Time Gates Open analysis).
- Of all fish that were tagged and lived in 1994 (all phases combined), 40% were blocked. (Data are not available for 1993.)
- Of all fish that were tagged and lived in 1998 (all phases combined), 24% (39/163) were blocked.
- Of all fish that were tagged and lived in 1999 (all phases combined), 9% (16/177) were blocked.

Citation:

Edwards, G. and K. Urquhart. 1996. Adult salmon migration monitoring during the various operational phases of the Suisun Marsh Salinity Control Gates in Montezuma Slough, September – November 1994. Stockton (CA):Department of Fish Game.